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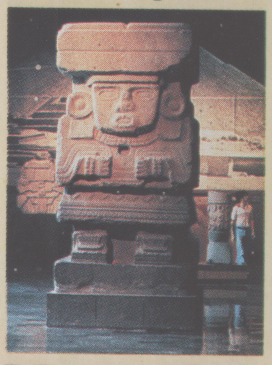
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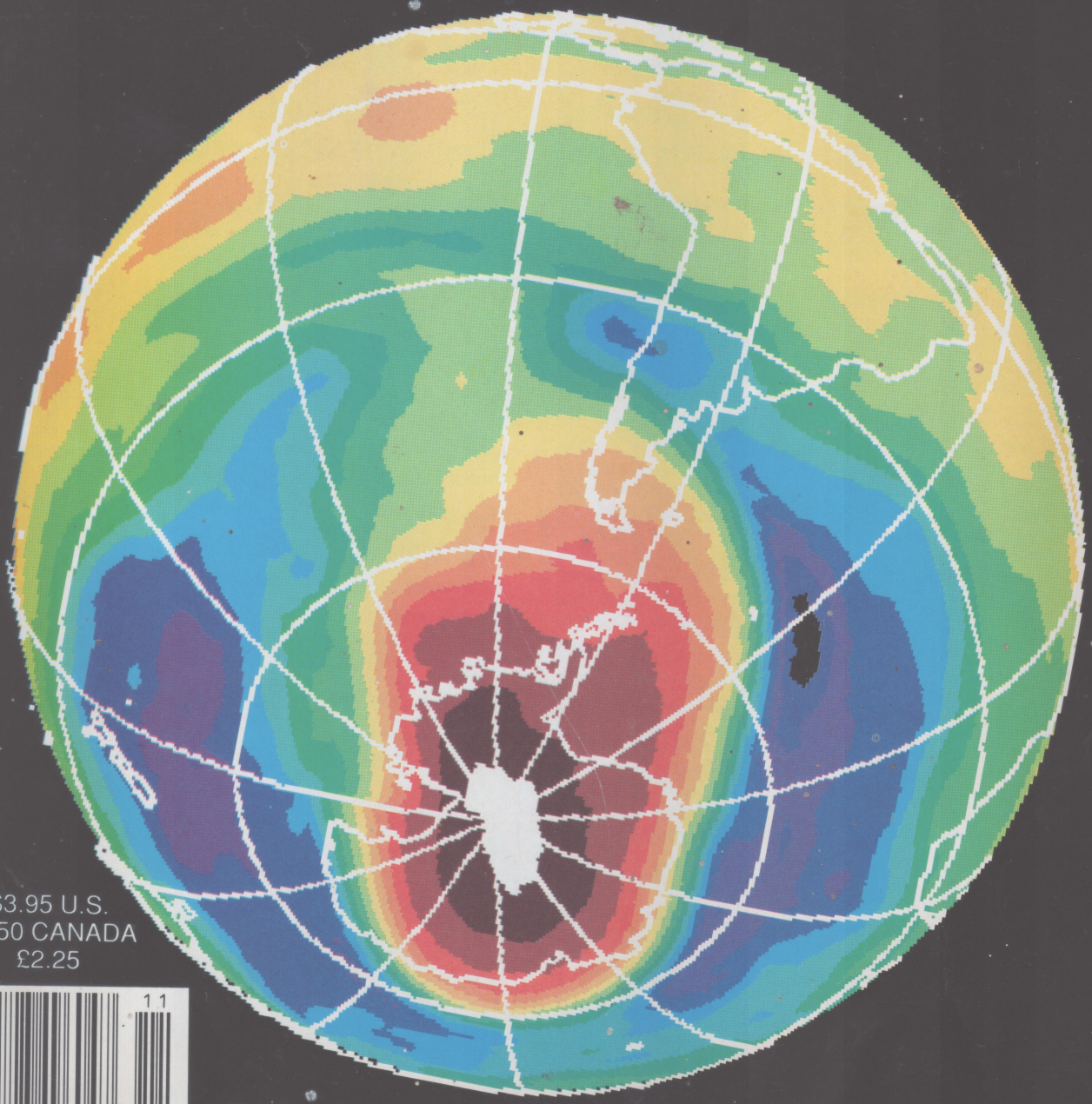
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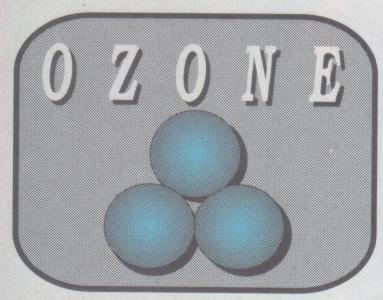
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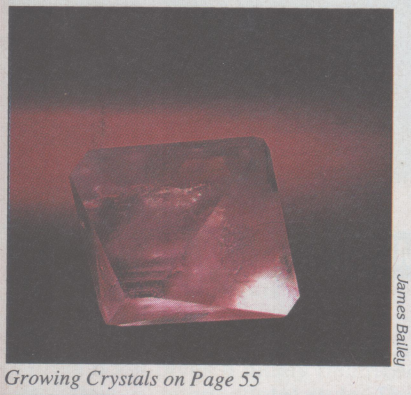
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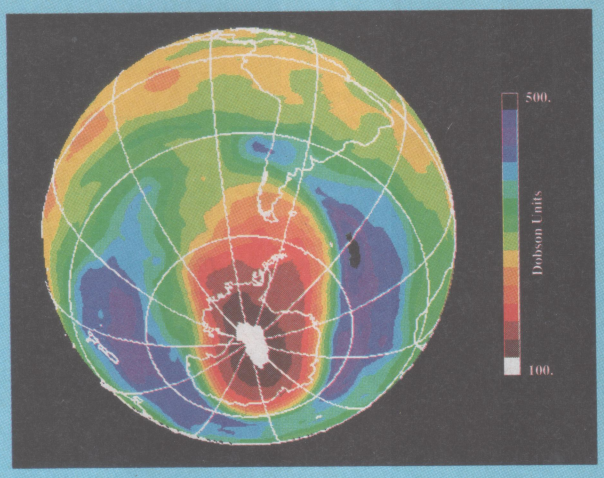
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ABOUT THE COVER



This ozone image of the Southern Hemisphere for October 5, 1991, shows the large region of depleted ozone over Antarctica known as the "ozone hole." Ozone is indicated by a rainbow color code in which red denotes low ozone and blue high ozone. (Courtesy NASA's TOMS Ozone Processing Team.)

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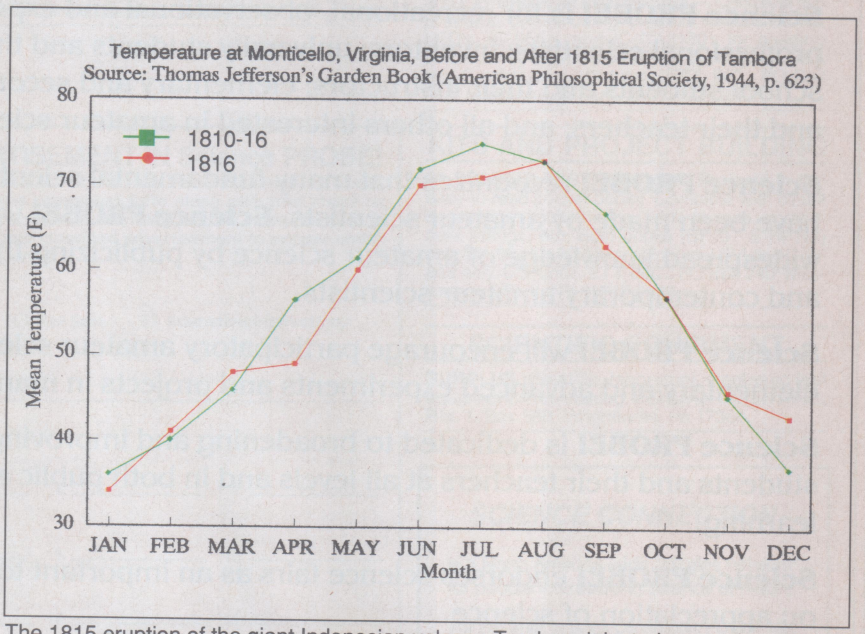
Thomas Jefferson is best remembered for writing the Declaration of Independence and his service as third president of the United States. He was also a self-taught naturalist, horticulturist, archaeologist and weather observer.

For many years Jefferson kept meticulous records about the climate at his plantation, Monticello. For example, every day he noted the minimum and maximum temperature. He also recorded the amount of rain and snow and the first appearance each spring of various birds, insects and flowers. Since Jefferson's time, many other amateur scientists have also kept detailed records of daily weather statistics and the variety and number of birds sighted. These amateur weather observers, astronomers and bird watchers have made important contributions to advancing knowledge.

These thoughts were very much on my mind during the weeks before a visit to Monticello last June. While looking over some of the climate records from Jefferson's "Garden Book" and touring the University of Virginia, which he founded, I became more convinced than ever that an ideal way to encourage interest in science, and possibly help reverse the decline in science education, is to encourage schools, families and individuals to keep permanent notebooks of observational data about their surroundings.

These observations would extend beyond routine wind, precipitation and sky reports to include a seasonal census of plants and animals. On what day did the first dandelion bloom appear? When did the first hummingbirds and purple martins arrive? What is the circumference of a particular tree in a yard, campus or park? The mean weight of 50 acorns from a particular oak? The mean breadth of 50 winged seeds from a particular maple?

If funds were available, observations could be expanded to include daily measurements with various weather instruments. A digital pH meter could be used to measure the pH of precipitation. Various sun photometers could be used to provide information about the atmosphere's optical thickness and the amount of solar ultraviolet.



The 1815 eruption of the giant Indonesian volcano Tambora injected so much sunlight-absorbing dust into the stratosphere that 1816 became known as "the year without a summer" in New England. Thomas Jefferson's detailed weather records clearly show the effect of Tambora on the mean temperature at Monticello, Virginia.

Observations like these provide a snapshot of the environment at a particular place and time. Climate changes, with or without the intervention of human beings. Therefore collections of seemingly routine observational data can provide an invaluable record for future scientists.

Schools and universities around the world could serve as focal points for nature archive programs. Many schools are already collecting limited information, and some share their data through computer networks. These efforts could be expanded to include a documented campus survey at least once each semester. A parallel survey could be conducted during field trips to a nearby park or natural area. Perhaps businesses and foundations would offer cash grants to schools with particularly good data collection programs.

Would schools and amateur scientists be interested in such a program? *Science PROBE!* recently announced the Science Probe Atmospheric Network (SPAN) to collect data about solar UV and ozone, and we continue to receive responses from teachers, university professors and both professional and amateur scientists. When I attended the Quadrennial Ozone Symposium in Virginia last June, scores of atmospheric scientists, including meteorologists and professors from Egypt, Japan, Russia and other countries, expressed serious interest in participating in SPAN.

Based on this response and the positive reaction of officials at various scientific and educational organizations, I am optimistic that a national or even international program of data collection by students and amateur scientists will be well received.

We will eventually publish guidelines for beginning your natural census. Meanwhile, there's nothing to keep you from beginning now. Whether you record your observations in an expensive computer or a 69-cent notebook doesn't matter. What's important is deciding what observations you can make and beginning now. ✳

Forest M. Mims, III

Our Charter

Science PROBE! is dedicated to the proposition that a broad and enthusiastic knowledge of science, whether self-taught or acquired in a classroom, is an essential element of a balanced education.

Science PROBE! is for recreational, observational and experimental amateur scientists; professional scientists; inventors; university students and their professors; technical school students and their instructors; elementary and secondary school science students and their teachers; and all others interested in amateur science.

Science PROBE! recognizes that many fundamental scientific discoveries and inventions have been made by amateur scientists. **Science PROBE!** will encourage a more widespread knowledge of amateur science by publicizing the achievements of historical and contemporary amateur scientists.

Science PROBE! will encourage participatory amateur science by publishing both elementary and advanced experiments and projects in many fields of science.

Science PROBE! is dedicated to broadening and improving the science education of students and their teachers at all levels and in both public and private institutions of learning.

Science PROBE! endorses science fairs as an important tool for giving students a hands-on appreciation of science.

Science PROBE! encourages and supports serious research by amateur scientists. **Science PROBE!** likewise encourages observational and recreational science activities, experiments, demonstrations and hobbies.

Science PROBE! will serve as a forum and an information clearinghouse for amateur scientists. **Science PROBE!** will receive, evaluate and publish significant observations and discoveries by amateur scientists.

Science PROBE! believes that experiments by amateur scientists should be conducted in a manner that will not endanger the property of others and the safety of onlookers. Experiments involving animals or people should be conducted with the highest regard for the safety and well being of the subjects.

Science PROBE! believes in ethical science and strongly opposes science fraud. **Science PROBE!** will not knowingly publish erroneous or fraudulent information. If information published in **Science PROBE!** is found to be false or fraudulent, **Science PROBE!** will promptly publish a retraction or correction.

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UPDATES & CORRECTIONS

Volcano Twilights

Fred Schaaf is a well-known astronomy writer. His most recent book, *Seeing the Deep Sky* (John Wiley & Sons, Inc., 1992), is a guide to stars, star clusters, nebulae and galaxies of the night sky. Schaaf is also a careful observer of the daylight sky, particularly volcano twilights, and he has sent us a lengthy critique of our coverage of the eruption of Mt. Pinatubo on June 15, 1991 (*Science PROBE!*, April 1992). Here are some of Schaaf's observations:

"Steve O'Meara's coverage of the eruption and aftermath . . . is excellent. . . . Then there is his sampling of sky observations. These are fascinating. . . . Quibbles: Bishop's ring doesn't have to be the most delicate of all atmospheric phenomena. I saw the colored band become quite prominent when observing the second major Mt. St. Helens cloud pass and in a number of El Chichon twilights. . . .

"Harry Helms' article was obviously meant to be an introduction to observing volcanic twilights. It was a very good job indeed. The improvements I would suggest [come] from the benefit of more experience with volcanic clouds —[although] Helms seems to have learned about volcanic twilights in 1991 more quickly than I did in 1980 and 1982, which may be partly due to El Chichon having improved the literature.

"Helms' eruption-by-eruption discussion of the history of studying volcanic twilights is very good but missing a few key components. . . . Helms and Mims seem to think the "bright corona" around the sun is Bishop's ring. But surely the term Bishop's ring has always been and should always be used to refer to the ring of color bounding the white or silver-white aureole.

"Mims' Pinatubo article goes into plenty of territory with which I'm not familiar, so was the most rewarding to me. . . . I was fascinated by some of his observations, which included a few effects I hadn't noticed — the dark band at the horizon and the obviously volcano-caused lunar corona. My only strong objections are to his use of the term "Bishop's ring" [to describe] the silvery-white aureole [which] is by no means rare or difficult to notice in the months following one of these great eruptions.

. . . The vast majority of what the articles have to say is right on target and by far the best and most extensive coverage of volcanic twilights in a magazine.

"Please understand that although I have pointed out things which could be clarified or amplified . . . the vast majority of what the articles have to say is right on target and by far the best and most extensive coverage of volcanic twilights in a magazine. You're doing a great service to get the word out and suggest observations of the phenomena produced by this marvelous event."

Schaaf's letter also addressed visible volcanic clouds and striations and noted that we wrote about volcano sunsets when "it is really the effect on twilights that is remarkable, complex, notable."

A Pinatubo Update

Forrest M. Mims, III, has made almost daily measurements of the atmosphere's optical thickness for more than two years. His post-Pinatubo observations with an inexpensive collimated detector equipped with a 1,000-nanometer filter closely match those made by satellite at the same wavelength and show that the peak sunlight absorption over South Texas occurred last September and October. From September to May there were many days when the output of a calibrated solar cell was 15% less than before the eruption.

The potential impact of this very high level of sunlight attenuation on climate is discussed in a paper by James Hansen and several other NASA scientists in the January 24, 1992, issue of *Geophysical Research Letters* (Vol. 19, No. 2). This same journal, which can be found in many technical and university libraries, features a collection of interesting scientific papers on Pinatubo's enormous atmospheric effects.

The Birthday Problem

In the April 1992 "Updates and Corrections," readers were invited to respond to Alex Brin's comments about the birthday problem posed by Carol Lewis in the July 1991 installment of *The Young Scientist*. Brin wrote that if 23, not 24, people attend a birthday party there will be a 50 percent probability two people will have the same birthday. For an 80 percent chance of a match, only 35 instead of 40 people are required.

Edward Viens of Menard, Illinois, has performed an analysis of this problem that takes leap years into consideration. He writes, "If we assume that a statistically insignificant number of people alive today were born before March 1, 1900, then the calculations can be based on one leap year every 1461 days.

"Using a Sharp EWL-506P calculator, I solved the problem [by calculating the probability of] non-coincidence for 23 and for 35 guests if none were born on a leap day, if one was born on a leap day, that a non-coincidental group of 23 and 35 guests would include one person born on a leap day, and non-coincidence overall.

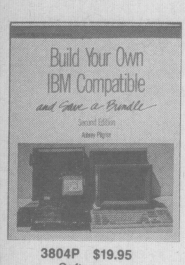
"My answers corroborate Alex Brin's solution. Twenty-three guests have a 50.3 percent probability of coincidental birthdays, and 35 guests have an 80.9 percent probability."

Viens also responded to Alex Brin's comment about the randomness of coin tosses. Brin wrote that, "The more times you flip a coin the less likely it is that you'll end up with half heads and half tails." Viens responds that this "ignores the obvious fact that any odd number of flips carries a 0-percent probability of half and half."

Egg Shells and Cells

In *The Young Scientist* for April 1992, Carol Lewis described a hen egg as a cell. George Triplett of Mahomet, Illinois, writes, "My memory of egg cells is that they include the world's largest cells. However, in the case of shelled

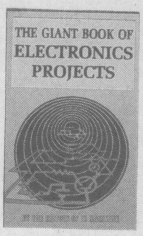
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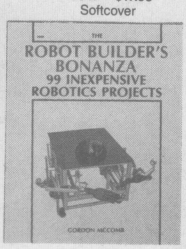
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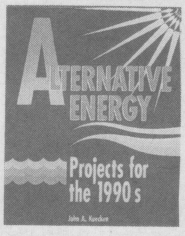
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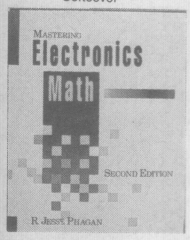
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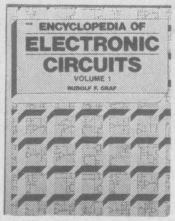
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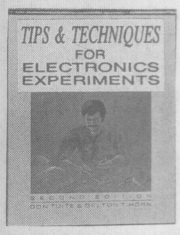
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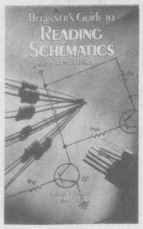
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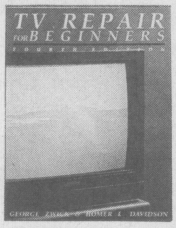
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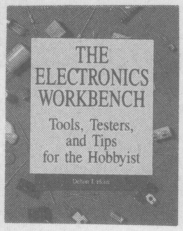
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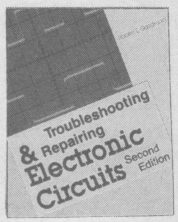
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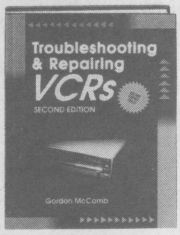
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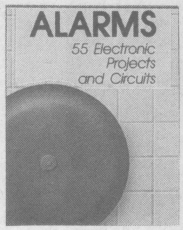
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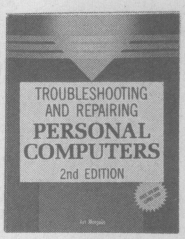
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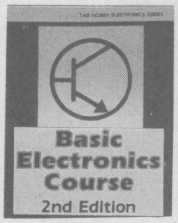
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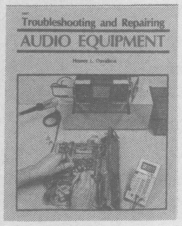
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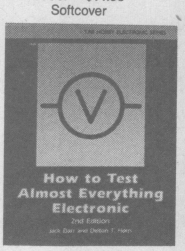
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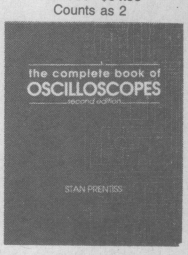
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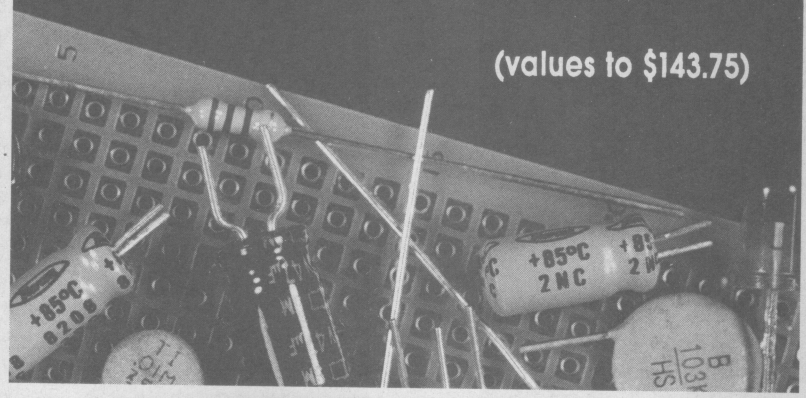
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LETTERS

Thanks for your many letters to Science PROBE!. *Though we cannot possibly answer all of them, we do read each one. We publish a representative selection of the letters we receive in the "Letters" and "Updates and Corrections" departments in each issue. Letters that are published may be condensed and lightly edited for clarity. Please let us know if you do not wish your letter to be published. — Editor*

Lunar Eclipse Watch

I would like to welcome readers of *Science PROBE!* to participate in a potentially historical astronomical observation.

On the evening of December 9-10, 1992, a total lunar eclipse will be visible from Europe, Africa, and the Eastern United States. Under normal eclipse conditions, sunlight passing through Earth's atmosphere above the terminator is refracted and scattered into the Earth's shadow. This causes the Moon's surface to glow dimly in red and yellow light during totality.

This December's eclipse, however, will not occur under normal conditions. Volcanic aerosols from the eruption of Mount Pinatubo should make our atmosphere less transparent to sunlight and thus affect the Moon's brightness. Historically, total lunar eclipses occurring months after major volcanic eruptions have appeared very dark.

The December 30-31, 1982, eclipse, for example, was exceedingly dark. The following account by Jean Bourgeois of Belgium was adapted from a letter in *Sky & Telescope* (June, 1983, page 485). He had descended Mount Everest and was on a high pass in Tibetan China waiting [for] the full Moon to rise. But the Moon "didn't appear!":

"Only after I discovered a thin crescent did it occur to me that a total eclipse was under way. . . . No trace of the obscured part of the lunar disk was visible. Even the edge of the umbra was colorless."

That eclipse occurred nine months after the eruption of El Chichon volcano in Mexico. Mount Pinatubo has spewed about twice as many aerosols into the stratosphere as El Chichon, assuring a dramatically dark eclipse. But there is only one way to be certain, and that is why I encourage everyone to watch December's eclipse and send their results to me.

Use the following Danjon scale to record the Moon's brightness:

- L = 0 Very dark eclipse. Moon almost invisible, especially at mid-totality.
- L = 1 Dark eclipse, gray or brownish in coloration. Details distinguishable only with difficulty.
- L = 2 Deep red or rust-colored eclipse. Very dark central shadow, while outer edge of umbra is relatively bright.
- L = 3 Brick-red eclipse. Umbral shadow usually has a bright or yellow rim.
- L = 4 Very bright copper-red or orange eclipse. Umbral shadow has a bluish, very bright rim.

Mount Pinatubo erupted violently last June, creating a dense stratospheric aerosol layer that stretches from latitudes 20 degrees north to 20 degrees south. Volcanic twilights have been recorded as far north as 50 degrees latitude. In the Southern Hemisphere, Pinatubo aerosols have been accompanied by those from a more recent eruption of Mount Hudson in Chile. Together they cover all southerly latitudes to about 70 degrees. Since it will take years before the stratosphere returns to normal (given no other volcanic disturbances), the December, 1992, total lunar eclipse should indeed be dramatic.

— Stephen James O'Meara
Cambridge, Massachusetts

Stephen O'Meara, a frequent contributor to Science PROBE!, *is fascinated as much by volcanoes as by astronomy. Send your lunar eclipse observations to him at 26 Montclair Ave.; Roxbury, Massachusetts 02131. — Editor*

Up with Statistics

Congratulations on publishing Dr. Hartwig's article on basic statistics (April 1992, page 59)! Not only have you told people the truth about a badly misunderstood area of mathematics, but you dared to do so with equations and real-world data, too. . . . The article was easy to read and understand, with very clear graphs. . . .

Folks like me who use the Apple Macintosh also have statistics software available. A Mac version exists for SYSTAT and four compatible supplements: $795 for SYSTAT and $110 per supplement. SPSS is also available for the Macintosh, while SAS Institute has JMP (which offers real-time data acquisition, according to SAS) for around $600. And Abacus Concepts has its StatView and SuperANOVA family of statistical analysis software, including a smaller Statview Student version for under $100 (street price in some areas). Macintosh publications like *MacWorld* and *MacUser* cover such programs on a fairly regular basis, so keeping tuned to your local bookstore or newsstand can come in handy. . . .

— Joel Alvin Christine
Tyrone, Pennsylvania

Mark Hartwig's article, "Basic Statistics for the Amateur Scientist" in the April issue was very interesting. You should know though that I tried to buy SPSS/PC+ Studentware from SPSS INC.; they won't sell it to individuals.

— Sanford J. Moos
Centereach, New York

Home-Built Equipment

I am looking for information and materials for home built equipment for the amateur interested in physics, optics, chemistry and biology.

I did find in a used bookstore, an old book published in 1960 by Simon and Schuster, titled "The Scientific American Book of Projects for the Amateur Scientist." This is a good example of what I am seeking, however this particular book is somewhat dated in that materials cited in construction plans are no longer available. I would like to find information which is more current or timeless. My particular interest is chemistry, the other disciplines mentioned and some not mentioned are necessary as means to an end in home construction techniques.

— Bruce Bailey
New Gloucester, Maine

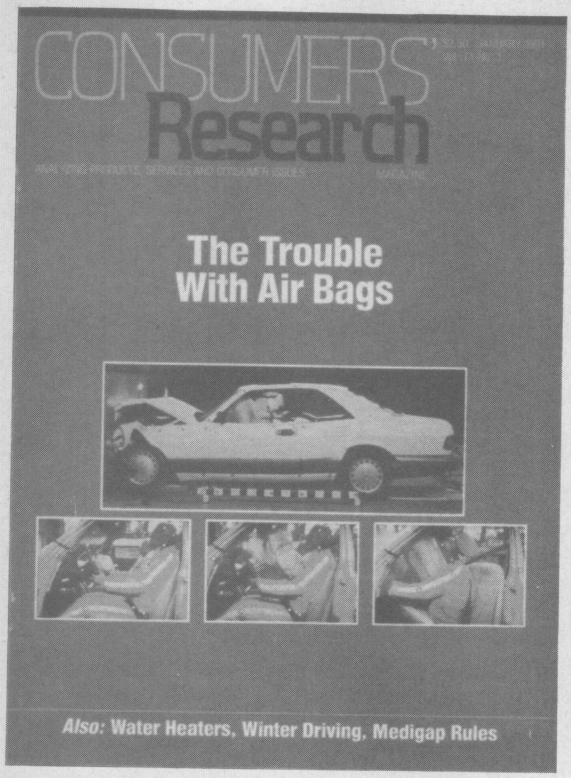
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PLEASE ALLOW UP TO SIX WEEKS FOR PROCESSING

An outstanding reference is Building Scientific Apparatus *by John H. Moore, Christopher C. Davis and Michael A. Coplan (Addison Wesley, second edition, 1989). Although this book does not cover chemistry, it does discuss glass blowing, vacuum techniques, and materials.* — *Editor*

Science Education

We share a common concern: the low science and math performance of students in our schools. You started *Science PROBE!* to combat this. I've tried to work with the local schools. You've been much more successful than I.

I'm a bench chemist at a local lab. Recently, we donated an older UV-VIS double beam spectrophotometer to a local school. Along with the instrument went numerous offers of help. It's been two years. The instrument is gathering dust, and no one's been called to help out. Is this above the level of a high school? . . .

Our school sponsors a science fair. What can a sponsor group do to encourage science fairs?

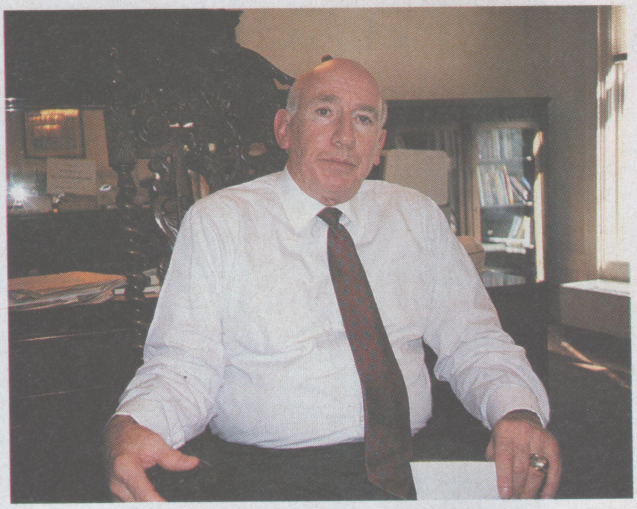
A few years ago, a friend and coworker of mine decided industry wasn't for him. He became a high school teacher, and shortly thereafter I became a science fair judge. He mentioned that many groups had good science programs, but, that as a teacher, he just didn't have time. My idea was to have local concerned citizens do the work and save the teachers time. Here's the problem — schools are very hesitant to let outsiders (even parents) in.

— Mark Andress
Polk, Ohio

Teachers, what went wrong? How can schools make effective use of the growing number of concerned scientists like Mark Andress, who are willing to volunteer time and donate equipment? Send us a concise list of suggestions; we will publish the best ones in a future issue. — *Editor*

Science Fair Advice

I read with interest the article entitled "You Be the Judge!" in the



Alfred McLaren, Science Service Inc.

"Science Fair Scene" column in the January, 1992 issue of *Science PROBE!* magazine. Having been involved in science fairs both as a participant and as a judge, I can relate to a lot of things mentioned in your article, and I feel that you did a great job with it. However, the sidebar entitled "For Judges Eyes Only!," a point [should have been made] that judges should in no way interfere with a student's display.

[Many years ago], I participated in the . . . International Science and Engineering Fair. . . . I had a very good project on the use of computers in chemistry, and the major focus of the display was an organic nomenclature program that I wrote. The program was originally for a PDP-11, but I wrote a new version for the PET microcomputer so that I could take a PET with me to science fairs and exhibit all of my programs.

For the first judging session, only judges are allowed on the floor. When the participants were allowed back into the exhibit area, I found that things had been taken from my display and, more importantly, the PET was on and the program in use wasn't working. All of the judges that saw me mentioned that my program didn't work — except one. He informed me that he decided he would see how good a programmer I was by deliberately placing an error in my program. . . .

While I am not saying that I would have won or would have received an award were it not for the actions of this judge, the fact remains that I'll never know how well I would have done at the ISEF.

The irresponsible actions of a judge can be devastating to a high school student — I had the misfortune of finding out the hard way. While it has not affected me professionally in the long run (I'm now a university professor), for someone else, the consequences might be different. I hope that you can inform potential judges about the repercussions of such actions, and that a judge should never take, alter, or in any other way interfere with a student's science fair display.

— John K. Estell
Berkley, Ohio

I happened to be a judge at the ISEF you cited. A few weeks before the 1992 ISEF, I met with Alfred McLaren, the new president of Science Service Inc., and Donald Harless, the vice president. I described your unfortunate experience of more than a decade ago, and both McLaren and Harless expressed great concern about the incident. They explained in detail the many steps they have taken to eliminate such problems, including better briefings for the judges.

Although McLaren has many new ideas of his own about improving the ISEF, he is very open to streamlining the bulging ISEF rules and reducing the number of forms required of participants.

Incidentally, McLaren is both a scientist with a Ph.D. and a former Navy submarine captain whose studies of the thickness of arctic ice have been published in various scientific journals. Based on two meetings I have had with him, I am optimistic that the ISEF will benefit greatly from McLaren's tenure at Science Service. — *Editor*

Volcanoes and Telescopes

I would like to compliment your April 1992 issue of *Science PROBE!*. I especially liked the articles about Mount Pinatubo and the Hubble Space Telescope.

— Charles Thomas Jr., Age 12
Yale High School
Yale, Oklahoma ✶



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News and Notes

By Mark Hartwig

VENUS ON-LINE

Have you ever wanted to explore Venus? Well, now you can, thanks to Magellan, NASA's Venus radar mapper. Radar images of Venus are now available in CD-ROM format from the National Space Science Data Center (NSSDC).

Magellan is a spacecraft designed by NASA to map the surface of Venus with imaging radar. The first U.S. planetary mission since 1978, it was launched from the space shuttle Atlantis on May 4, 1989, and began orbiting the planet August 10, 1990.

During its first 8-month mapping cycle, Magellan obtained images of 84 percent of Venus's surface. Data from the Magellan will allow the first global geological analysis of Venus, letting researchers catalog the volcanic, tectonic and erosional processes shaping the planet.

Because of thick carbon dioxide clouds that surround Venus, Magellan uses radar rather than optical instruments. In particular, Magellan uses a special radar system called synthetic aperture radar (SAR). Unlike conventional radar, where image resolution depends on the physical size of the radar antenna, SAR uses the spacecraft's motion to simulate a large "synthetic" antenna — one much larger than Magellan's 3.7-meter (12-foot) antenna.

As a result, images from Magellan are much more detailed than those from previous missions. According to NASA's Jurrie Vanderwoude at Jet Propulsion Laboratory, radar images from the Magellan have a resolution of 120 meters (about 131 yards) — which means that the smallest visible objects measure about 120 meters in size. By contrast, images from the earlier Soviet Venera missions have a resolution of only about 1.9 kilometers (about 1.2 miles).

Images from the U.S. Pioneer Venus spacecraft had an even lower resolution of about 97 kilometers (about 60 miles).



Courtesy of Public Information Office, Jet Propulsion Laboratory

False-color perspective of western Ishtar Terra in the northern hemisphere of Venus. The vertical scale has been exaggerated 23:1.

Magellan is currently in an elliptical orbit that takes it as close as 294 kilometers (182 miles) and as far as 8,543 kilometers (5,296 miles) from the planet. The spacecraft completes one orbit every three hours and 15 minutes. During each pass near the planet, the SAR images a strip between 17 and 28 kilometers (10 and 17 miles) wide. Each strip begins near the north pole and continues into the southern hemisphere.

As the spacecraft moves away from the planet, it turns its antenna toward Earth and sends the data collected during the imaging. It then continues its orbit for the next imaging swath.

Because Venus rotates once every 243 Earth days, each pass takes in a different swath that overlaps slightly with the previous one.

Images from Magellan's first mapping cycle are now available on compact disks from the NSSDC at the Goddard Space Flight Center. The images, which fill about 50 disks, cover 84 percent of the planet's surface. The charge is $20 for the first CD-ROM, and $6 for each additional disk. The NSSDC waives this charge for bona fide research users, government laboratories and teachers who indicate that they cannot afford to purchase the disks.

The NSSDC also provides four different software packages for displaying and processing the Magellan images — one for IBMs and compatibles, and three for the Macintosh.

For more information on the CD-ROMs, contact the NSSDC at (301) 286-6695, or write to the National Space Science Data Center, Goddard Space Flight Center, Greenbelt, Maryland 20771.

Those with access to Internet can obtain individual images by accessing NASA's computer at the Ames Research Center in California (AMES.ARC.NASA.GOV).

The Ames site has two CD-ROM drives that are accessible through the pub/SPACE/CDROM and pub/SPACE/CDROM2 directories.

Special thanks to Ronald Baalke, at Jet Propulsion Laboratory, for information about the NSSDC CD-ROMS.

Making Do: Packing It In

Being a scientist frequently means working with expensive, specialized tools. But what if the tool you need doesn't even exist?

That's the question Paul Schlichta faced when he needed a way to measure the electrical resistance of powder as a function of its packing fraction — or how tightly packed it is.

A chemist with Jet Propulsion Laboratory (JPL) in Pasadena, California, Schlichta was given the task of synthesizing a powdered form of fluorine-doped tin oxide (SnO2:F) — a material JPL needed for a special lead-acid battery it was making.

Originally synthesized as a thin film on glass fibers, SnO2:F was not only a good conductor, but highly resistant to acid corrosion — a rare and attractive combination.

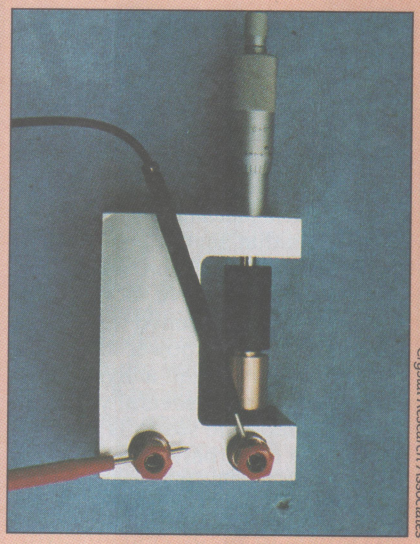
Schlichta's job was to create a powdered form of SnO2:F that retained the desirable properties of the thin film. Although some people at JPL thought it couldn't be done, it wasn't long before he produced a batch.

At that point, however, he hit a snag: there was no way to measure the powder's conductivity. To make matters worse, there was little money in the budget to have an instrument developed. So Schlichta knew what he had to do. "I figured that by the time I could get somebody to design something for me at JPL — a very expensive process — I could make something better myself."

In the course of an afternoon, Schlichta created his new instrument, which is "just a micrometer with a bunch of copper fittings in it — copper and plastic fittings." (See photo above.) This instrument allowed him to measure the conductivity of the powder under varying degrees of compaction.

Using the device is fairly simple. An empty sample cup is placed in the micrometer, which is then closed until an attached ohmmeter registers a slight electrical resistance. Next the ohmmeter is set to zero, which cancels out the resistance registered by the cup. Then the cup is removed, weighed, filled with powder, and weighed again. (Weighing the powder allows the researcher to estimate its relative density as it is compressed.)





Crystal Research Associates

Chemist Paul Schlichta with his resistance gauge, shown enlarged at right.

Next the sample cup is put back into the micrometer, which is tightened until the ohmmeter registers a measurable resistance. The micrometer is then tightened in small steps, with the researcher recording both the resistance and micrometer reading after each step.

The resulting values can then be entered into a simple spreadsheet program, which calculates the powder's packing fraction and resistivity. (In general terms, packing fraction is the relative density of the compressed powder compared to 100-percent dense material. Resistivity is the electrical resistance across the opposite faces of a one cubic centimeter cube of the compressed powder.)

For Schlichta, the challenge of improvising is part of what makes science fun. An "amateur lab man from the about age of 10," Schlichta is accustomed to fashioning his own tools and equipment. That experience put him in good stead when he won the 1948 Westinghouse Science Talent Search. It also helped him at Jet Propulsion Laboratory when budgets or time-lines precluded using "professional equipment."

Schlichta believes that improvising is becoming a lost art in scientific research. "That's what's gone out of things. The current generation, with one exception — computers — isn't doing that. They're not getting their hands dirty." He also believes that "there has been too much of a spirit of 'let's go out and buy a nice $50,000 or $100,000 apparatus to do the job with.'"

Because of his enthusiasm for hands-on science, Schlichta became a regular judge at local science fairs. Even when he wasn't judging, he would often attend anyway. He had discovered that science fairs were a good place to find competent technical assistants.

Schlichta is also a big promoter of the Westinghouse Science Talent Search — not only for the experience it provides, but also for its other benefits. "I was astonished," Schlichta says, "at the number of scholarship offers I got from people who thought I was merely an honorable mention.

Even an honorable mention — just the fact that you participated — very often singles you out for attention. So to go in for the STS and not make it is still a very impressive credential. It means you have the guts to do a project, the guts to take the test and prepare for it. It doesn't matter if you're not a finalist."

Paul Schlichta has recently retired from JPL and formed his own company. Among other things, he is marketing a modified version of his resistance gauge that can better withstand the pressure of pushing down on the powder.

For information about his device, write to:

Paul Schlichta
Crystal Research
1441 Sunnyside Terrace
San Pedro, California 90732

Or call (213) 831-0760.

Geomagnetic storms continue

Is the sky falling? No, but it may cause some problems for a while.

A NOAA (National Oceanic and Atmospheric Administration) scientist says that severe geomagnetic disturbances, which last year interrupted short-wave radio transmissions and threatened to interfere with electrical power distribution and other human activities, could continue for several years.

A geomagnetic storm is a worldwide disturbance of the Earth's magnetic field caused by particles emitted from the sun. According to Dr. Jo Ann Joselyn, research liaison officer for NOAA's Space Environment Laboratory in Boulder, Colorado, the number of geomagnetic storms is often greatest when sunspot activity — the generally accepted indicator of solar intensity — is in decline. Such activity, she says, increases and decreases in roughly an 11-year cycle. The present cycle is now past its time of maximum activity.

Joselyn says that although the sunspot cycle entered its maximum phase about three years ago, a meaningful increase in the annual count of geomagnetic storm days began only in March of last year.

A frequent result of geomagnetic storms is the aurora borealis, or the Northern Lights. Another result, however, is trouble. For one thing, geomagnetic storms can interfere with high frequency communications. The enhanced auroras can also wreak havoc on radar signals — either scattering the signals and producing a garbled image or reflecting them back and producing a false "target."



Photo courtesy of National Aeronautics and Space Administration

Near sunspot maximum, small flares occur several times a day and major ones once every few weeks.

A particularly strong geomagnetic storm can induce sudden power surges in electrical utility lines, damaging equipment and causing blackouts. A spectacular example of this occurred March 13, 1989, when a major disturbance blacked-out virtually the entire Canadian province of Quebec, and caused extensive damage to power transformers in Canada and the United States.

Below ground, currents induced by even minor disturbances can cause noticeable corrosion in metal pipelines.

Up in space, the disturbances are a threat to electronics aboard satellites. Geomagnetic storms also heat the Earth's atmosphere, causing it to expand.

This places increased drag on satellites in low orbits, causing them to drift out of orbit. Skylab fell victim to this effect in 1979, when its orbit decayed and it came crashing back to earth.

There were 36 days in 1991 with major geomagnetic storms. This ties the record set in 1960 for the largest number of major storm days in 60 years of observations.

Science PROBE! Network Spans the Globe

Amateur scientists from all over the world have applied to be part of the *Science PROBE!* Atmospheric Network (SPAN), which will become an international network that collects information about the atmosphere.

SPAN participants will monitor the Sun's ultraviolet radiation (UV-B), total ozone, volcanic haze, precipitable water and other atmospheric parameters. Each person or organization will send observations by computer or mail. Data from all observation sites will be compiled and made available to anyone with a computer or modem.

Daily measurements will be made by each participant. To ensure that data is consistent, *Science PROBE!* will coordinate initial equipment callibration and act as a resource for those considering construciton of a SPAN device.

Read more about ozone monitoring in "Tracking Ozone" beginning on Page 32 and a special installment of "Science Experimenter" on Page 45.

If you would like more information about the network and an application form, send your name, address and phone number along with a note expressing your interest and a stamped, self-addressed envelope to:

SPAN
P.O. Box 11250
Fort Worth, Texas 76110.

If you have already submitted your application, we will be contacting you within the next few months to give you more details about the program.

Building a better bike

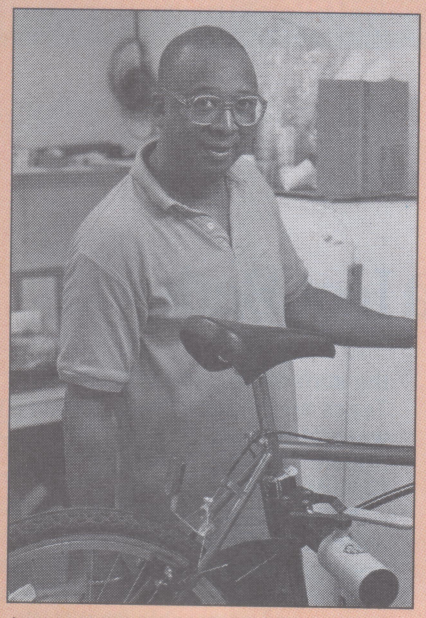
His friends laughed at it. An official at Schwinn called it "the answer to a question nobody ever asked." It appeared in *The Wall Street Journal* article on strange and unlikely ideas. But Bill Becoat's two-wheel drive bicycle may very well be the wave of the future.

According to Richard Klein, a mechanical engineering professor at the University of Illinois who has studied the theory of bicycles for more than 10 years, two-wheel drive is "one of the few major advances in bicycle technology of the 20th century." With Becoat's bike, that advance has become reality.

Becoat, a former construction worker from Alton, Illinois, first thought of the idea when his son's bicycle chain kept coming off the rear wheel sprockets. He wanted his son to be able to pedal home even if that happened.

Says Becoat, "I remember sitting on my front porch thinking, 'What's this chain business?' And I began to think of other ways to power the bike."

Eventually, he hit on the idea of using a speedometer cable to power the front wheel. But the first model was still pretty crude, Becoat says, and "didn't look good at all." His friends were not impressed — and neither were officials at Schwinn Bicycle Co. When Becoat took a prototype of his bike



Inventor Bill Becoat in his shop.



Becoat's two-wheel drive bicycle.

to Schwinn, he was virtually laughed out of the front office.

Worse yet, when *The Wall Street Journal* did an article on strange ideas and inventions, a spokesman from Schwinn used Becoat's bike as an example. "I was floored," Becoat says.

Far from discouraging him, however, the criticism only made Becoat more determined to succeed. Having heard of Professor Klein's work with bicycles, Becoat showed up with his new bike at Klein's lab. Klein told him that the idea had merit, and encouraged him to keep working on it.

Klein also offered some suggestions for improving the bike — such as using stronger materials for the drive shaft. And because the front wheel travels a greater distance around turns than the rear wheel, he thought the front and rear wheels should turn independently of each other.

A year and a half later, Becoat produced a working model, which he patented and began producing. Last September, at the international Interbike Expo in Anaheim, California, he rang up a reported $1.2 million in sales — to dealers from as far away as Finland, Australia and the Philippines.

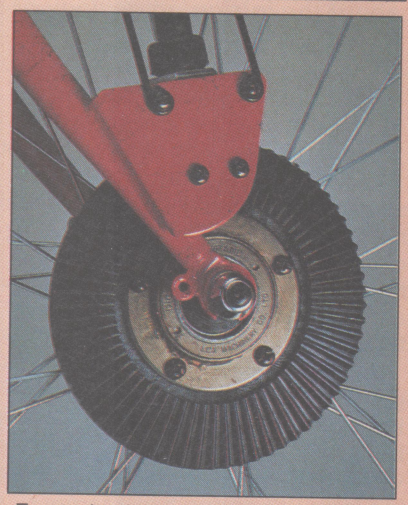
Klein believes that it's only a matter of time before two-wheel drive becomes a major force in the bicycle market. It offers significant advantages over traditional bikes. For one thing, two-wheel drive bicycles are much easier to pedal. In part, this is because two-wheel drive reduces tire slippage. But there are other reasons, as well.

One problem with rear-wheel drive bicycles is that the tires tend to deform in a way that creates excess resistance. According to Klein, this happens to all air-inflated bicycle tires when the back wheel is "pulled by the drive and the front wheel essentially is pushed. The two work against each other." Two-wheel drive dramatically reduces this effect.

Two-wheel drives are also much more stable, especially on snow and gravel. On rear-wheel drives, the front tire has a tendency to stop rolling when it hits gravel or snow. This makes the bike hard to control, and often leads to spills. On two-wheel drives, the front wheel keeps turning, increasing the rider's control.

Still, two-wheel drive is not without drawbacks. The drive train does increase the bike's weight — a real no-no for many cyclists. And, it is less efficient than traditional drive trains. But Klein points out that these drawbacks are more than offset by the sharp reduction in rolling resistance and slippage: "People who object to these things aren't thinking correctly. They aren't looking at the whole picture, because you actually spend less energy with a two-wheel drive bike."

"There is still a lot we don't know about bicycles," Klein says.



Front wheel assembly: Bill Becoat's bicycle transfers power to the front wheel by means of a flexible shaft.

"They can behave in surprising and counter-intuitive ways. And you have to be willing to listen to what reality is telling you. Critics say, 'Oh, that's absurd.' But the purpose of science is to take the intuitional knowledge that we have and replace it with scientific observations, with what reality tells us."

Becoat and Klein agree that when critics actually try the bike, their skepticism vanishes. "They ride it," Becoat says, "they stop scoffing." ✳

ABOUT THE AUTHOR

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By Harry Helms

Mother Nature Makes You a Hot Bath

Summary

Deep below the Earth's surface in many areas of the world, you'll find a hidden body of water. It's nature's way of letting off steam and giving amateur scientists some clues about the intriguing geology of the region.

Imagine that you're hiking in the back country on a hot, dusty summer day. Though you've got some water in your canteen, something a bit colder to drink would really be nice. And you're in luck, because ahead you see water flowing from a rock formation. It's a spring — and the icy water from it would sure taste great.

You make your way toward it, eagerly stick your hand into the flowing water . . . and immediately jerk it back in surprise. Instead of the icy water you expected, the water flowing from this spring has a temperature of over 37° Celsius (100° Fahrenheit)! You've just run across a *hot spring.*

Hot springs are the most common of all *geothermal* (meaning heat from the Earth) phenomena, and are found in areas of the world, such as the eastern United States and central Europe, where no other geothermal phenomena (such as volcanoes) are present. In some parts of the world, the water from hot springs is used to heat homes and produce electrical power. More commonly, they are popular as health spas and resorts where visitors can soak for hours in their warm, mineral-rich waters.

To amateur scientists, hot springs give fascinating clues about what's going on in a place we can seldom observe directly — below the Earth's surface. Let's take a closer look at hot springs and the processes that produce them.

Water Tables, Aquifers And Springs

The water in oceans, lakes and rivers makes up only a fraction of the Earth's water. Vast amounts are found underground. When rain and snow fall onto the ground, water seeps into cracks and openings in the soil. Even relatively "solid" surfaces, such as rock or dense clays, are filled with cracks, faults and other openings through which water can penetrate.

In some parts of the world, water from hot springs is used to heat homes and produce electrical power.

Some water stays near the surface, held by the soil or in smaller voids by capillary action. The remaining water, however, "percolates" downward until it reaches a point where the openings in the rock are filled with minerals, or just compacted too tightly for water to penetrate.

This is known as the *impervious* or *non-porous* zone. Over time, water accumulates above this zone and often in large quantities. The point where the accumulated water is first found is called the *water table.*

The water table is not at a constant depth all over the world. In marshy and swampy areas, the water table is, for all practical purposes, at the surface of the Earth! In most places, it is found within a few meters of the surface. However, in arid regions such as deserts, the water table may be over 100 meters (330 feet) below the surface. In parts of western Texas and eastern New Mexico, the water table may be more than 300 meters (1000 feet) below the Earth's surface.

A hole drilled or dug down to the water table results in a well. If the underground region between the water table and the impervious zone is porous and permeable (that is, it can let liquids move easily) and water can easily flow from wells drilled into it, that region is said to be an *aquifer.* Aquifers are often referred to as "underground streams." That's misleading, because aquifers are more than just water.

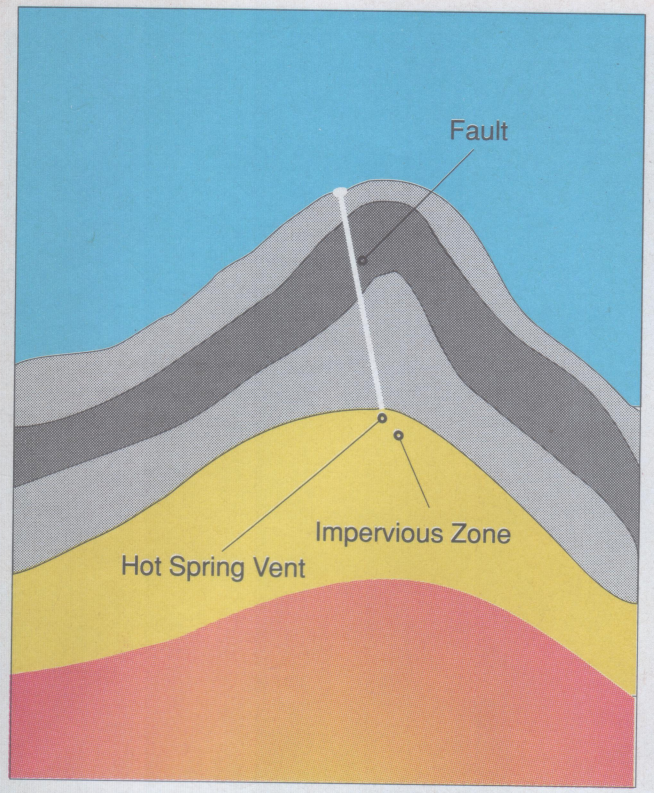
They include solids that water can flow through, so perhaps a better way to visualize an aquifer is as an underground "sponge" with water moving through it. The water in an aquifer is in motion because gravity pulls the water table down. But the effect on the aquifer is a bit like what happens when you press down on a full tube of toothpaste. If you push down at one point on the tube, you force another point of the tube upward.

When this happens in an aquifer due to gravity, water is discharged from points of the aquifer where the water table is near the Earth's surface. These points are what we refer to as *springs.*

Springs are often found on the sloping sides of hills and mountains. The folding and faulting processes that lift the Earth's surface to create hills and mountains also mean the impervious rock zone can be displaced and lifted above the surrounding terrain.

As water descends down through the hill or mountain, it can encounter the impervious zone before it reaches the bottom of the hill or mountain.

In such a case, water can be diverted in a "sideways" direction out through the slope and emerge as a spring. In other cases, springs are



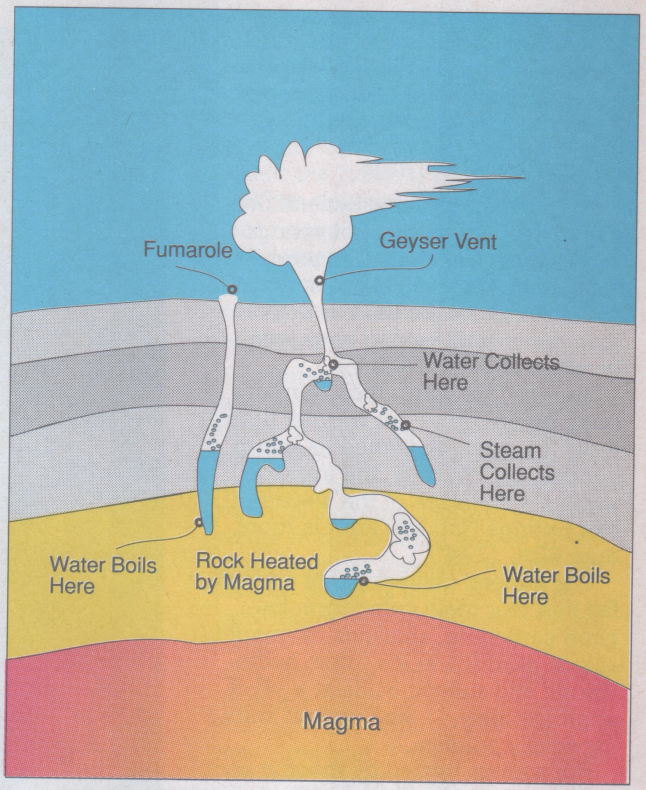


Figure 1 (left). This diagram shows how folding and faulting can work together to produce a hot spring. The fault in the mountain allows water to penetrate to greater depths than it ordinarily would. The water is heated by the Earth's natural temperature increase with depth. The water is also compressed as it works its way down the fault, which heats it further. The water is eventually forced out when it encounters the impervious zone under the mountain. **Figure 2** (right). The "plumbing" of a fumarole is much simpler than that of a geyser, but both allow water to descend to a depth where it can be heated to steam by magma.

found on more level ground. The water from such springs is forced to the surface vertically, much like an artificially-drilled well. Such springs are called *artesian springs*.

The rate of water flow from a spring varies with the porosity of the aquifer and the amount of precipitation feeding it. Some springs, particularly in arid regions, go dry during some parts of the year. If the flow of water from a spring is slow or sluggish, the spring is sometimes called a *seep*.

Many springs yield water of exceptional purity. Other springs flow from aquifers having water-soluble rocks. Some of the rock gets dissolved into the water, and the flow is known as a *mineral spring*. The waters from mineral springs often have distinctive flavors because of their mineral content, and are popular as drinking waters.

The processes that produce springs seem straightforward. But, there's one question we haven't answered yet — why is the water from some springs hot?

Nature's Hot Water Heaters

One of the most widespread misconceptions about hot springs is that all are the result of water heated by near-contact with molten magma underground. If it were true that all hot springs were magma-heated, every hot spring would be the site of a potential volcanic eruption! Although some hot springs are indeed heated by magma, most are the result of more mundane methods of heating underground water that have no connection to volcanic activity.

The Earth's temperature increases with depth. The rate of increase is normally 1°C for each 30 to 60 meters of depth (1°F for each 50 to 100 feet of depth). In most springs, the aquifer is not at a depth sufficient to heat the water noticeably. However, water can penetrate to great depths along fault lines or folded (usually mountainous) terrain. Not only does the water penetrate to depths where it can be heated, it remains at depths where it is heated for a sustained period of time.

Water can also be heated underground without having to penetrate to great depths. Water, like other substances, is heated when it is compressed. (This is why an air pump gets warm when used it to fill a bicycle tire or basketball; the compressed air heats up, which in turn warms the pump.) Often water is compressed in the narrow faults or folded rock, causing the water to be heated.

Water can be heated both by compressions **and** by descending to great depths. Figure 1 shows how this can happen, with water entering a mountainside through a fault or large crack and then descending until it encounters the impervious zone. The water then moves laterally toward a vent on the side of the mountain at a lower elevation. Along the trip down and to the vent, the water is also heated by compression.

Together, these processes can be thought of as a sort of natural water heater, and are responsible for the majority of hot springs in the continental United States, such as those

at Hot Springs National Park in Arkansas. In Europe, the most famous hot springs are found at Baden-Baden and Wiesbaden, Germany.

Mineral Hot Springs

The temperature and mineral content of the waters from hot springs vary widely. Generally, the term "hot spring" is restricted to springs whose water temperature is greater than the normal human body temperature of 37°C (98.6°F).

Springs less warm than human body temperature but warmer than tepid are often described as *warm springs*. By contrast, the average water temperature of the waters at Hot Springs National Park is more than 62°C (144°F).

The mineral content of hot springs fall into four main categories: calcium carbonate, alkalines (primarily silicon dioxide), acids (often hydrochloric and sulfuric acids at a pH of approximately 4), and various salts, especially halides.

Hot springs heated by magma are common in active "hot spot" areas such as those found in Iceland, New Zealand, Italy, Japan and the Kamchatka peninsula of Russia.

In the United States, such hot spots are found in Yellowstone National Park, the Snake River plain of Idaho, along the Rio Grande in New Mexico, near Bend, Oregon, on the southern end of the Salton Sea in southern California, and in Lassen National Park in northern California. Other hot spots are found near most active volcanoes in Oregon, Washington, Alaska and Hawaii.

A "hot spot" is an area where magma is located a relatively short distance from the Earth's surface. Sometimes hot spots are locations of recent volcanic activity (as in Alaska, Hawaii and Lassen National Park) but others, such as Yellowstone National Park, have not experienced any volcanic activity in several centuries.

Springs found in hot spots are generally hotter than those produced by the effects of compression or depth. In fact, many hot springs in hot spots are too hot for bathing (sometimes boiling) and the unwary can find themselves scalded.

Steam is often emitted with the hot water, along with various other gases. The most common other gas is hydrogen sulfide, which has a distinctive "rotten egg" smell. If the amount of hydrogen sulfide is high, the opening or vent of the hot spring can be surrounded by accumulations of sulfur.



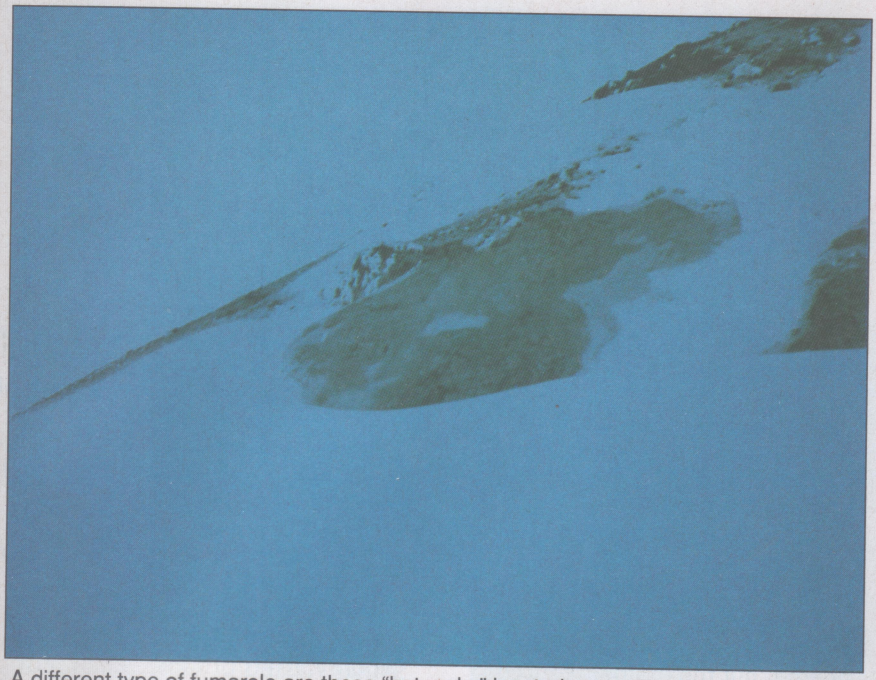
A classic fumarole located along the rim of the Kilauea volcano in Hawaii. The entire Kilauea caldera is dotted with numerous fumaroles, some of which have sulfur deposits around their vents.

Water from magma-heated hot springs usually has higher concentrations of minerals than other hot springs; the higher temperatures of these waters allow them to hold more minerals. Calcium carbonate is common, along with sodium and calcium chlorides. Even metals such as copper and zinc are found in some springs. There have been some attempts to extract such minerals from hot springs, although these have generally not proven to be economically viable.

As mineral-rich waters cool after venting from hot springs, the minerals (such as calcium carbonate) are often deposited in such shapes as cones and terraces. Yellowstone National Park has several spectacular mineral deposits around its hot springs.

Fumaroles, Geysers and Mudpots

Hot springs heated by magma are closely related to fumaroles, geysers and mudpots. *Fumaroles* are better known simply as steam vents, and are generally identical to hot springs except that the water is in the form of steam. Fumaroles are common along active volca-



A different type of fumarole are these "hot rocks" located at an elevation of about 3,150 meters (10,500 feet) on the southern face of Oregon's Mount Hood. This view is looking down from the Hogsback Ridge just below the summit. I and the other members of my climbing team had to pass just above this area on our ascent route, and despite temperatures of -9° Celsius (15° Fahrenheit) we could clearly see water boiling on the surface of the rocks and hear hissing sounds. And, there was a powerful rotten egg smell!

noes; the slopes of Hawaii's Kilauea volcano is dotted with literally hundreds of fumaroles.

Many active volcanoes in the Pacific Northwest, such as Oregon's Mount Hood and Washington's Mount Baker and Mount Rainier, have fumaroles near their summits.

Mountain climbers attempting those peaks can see the exposed, ice-free vents of fumaroles standing out in stark contrast to the snow and ice covering their summits. Moreover, the unpleasant smell of hydrogen sulfide is often strong on the upper elevations of such mountains because of fumaroles.

Geysers are something of a cross between a hot spring and fumarole. The underground "plumbing" of a geyser is complex, with many areas that trap water and steam. Figure 2 shows a cross-section view of both fumaroles and geysers. As you can see, the main difference is in the complexity of the "plumbing" and the number of places where water and steam can accumulate.

The lower depths of the geyser's plumbing develop large accumulations of steam, but the water in regions nearer the surface remains liquid. The pressure of the steam build-up eventually becomes too great, and the geyser empties itself in a jet of scalding water and steam. Water then begins to seep back into the geyser, and the process repeats.

Perhaps the most famous geyser is Old Faithful in Yellowstone National Park, which erupts at intervals of approximately 65 minutes. Most geysers have longer periods between eruptions. For example, some geysers in Iceland go several days between eruptions.

Mudpots are hot springs that do not flow from a clearly defined vent or opening. Instead, their water flows through the soil at the surface, creating an area of warm, often agitated mud. Sometimes the result is a *mud volcano*, in which mud takes the place of magma to form a cone-shaped mud formation, usually about 1 meter (1 yard) high.

Hot Springs as Energy Sources

As mentioned earlier, hot springs heated by magma are also geothermal energy sources used for heating and energy production in many active volcanic fields around the world. For example, in Iceland steam from hot springs is used to drive generators to produce electricity, and water from such springs is used to heat homes and greenhouses. Hot springs are also used to generate electricity in New Zealand and the Asiatic regions of Russia.

The Big Island of Hawaii has enormous geothermal energy potential, and research is underway to find methods of tapping it without causing damage to the island's unique and fragile environment.

In the continental United States, several geothermal fields near the Salton Sea in southern California's Imperial County are being developed for power generation.

A dozen geothermal electric power generating stations are currently in operation there, and the U.S. Geological Survey estimates that the Imperial County fields could eventually generate 6,800 megawatts of electricity. Another area of exceptional geothermal energy potential is the Newberry Caldera near Bend, Oregon.

Though geothermal electric power generation is not currently price-competitive with power generation through fossil fuels or nuclear energy, it is more "environmentally gentle" than such other methods. Unfortunately, the United States does not have enough geothermal fields to enable geothermal resources to play a major role in supplying our national energy needs.

I mentioned at the beginning of this column that hot springs can be found in areas with no other geothermal activity. These non-magma produced hot springs are common in hilly and mountainous areas (especially in the Appalachian and Ozark Mountains) and along fault lines (such as the New Madrid fault in Missouri). A logical starting point to locate ones near you is a book describing the geology of your state or region. Another good source to consult would-be camping, hiking, outdoors, and travel guides for your state or region. In many cases, such outdoor and travel guides give you more information about hot springs near you than geology books will.

Because hot springs are so common, many geological guides to an area will not cover all hot springs in

Continued on Page 126

By Carol Lewis

The Many Faces of Energy, Part II

Summary

The conservation of energy is one of the most basic and important laws of science. This law says there is a certain amount of energy, and that amount never changes. We can't make energy, and we can't destroy it.

In the last column, we explored the question, "What is energy?" We found out that energy comes in many forms, and that it often changes from one form to another. In this column, we'll see that energy can't be created or destroyed. We'll also take a look at some other ideas that are closely related to energy — momentum, work and something called entropy.

Energy IS Law-Abiding!

The conservation of energy is one of the most basic and important laws of science. This law says there is a certain amount of energy, and that amount never changes. We can't make energy, and we can't destroy it. (However, as we know, it does change its form almost constantly.)

A famous physicist, Richard Feynmann, told an interesting story to help his students understand the conservation of energy law a little better. He imagined a child — let's say a little girl — with a set of 28 blocks that were indestructible and couldn't be divided into pieces. Every block was exactly the same as all the others.

The girl's mother put the little girl into a playroom every day with the 28 blocks. At the end of the day, the mother counted the blocks carefully and discovered a law: No matter what the little girl did with the blocks — whether she built a bridge or balanced them on her head or threw them around the room — there were always 28 at the end of the day!

One day the mother found only 27 blocks, but she looked under the rug and found the missing one. This told her that she had to look everywhere to find all the blocks.

Once she found only 26 blocks. As she investigated, the mother found that the window had been left open and 2 blocks were outside! On another day, 30 blocks appeared, but the mother realized that a friend had come to visit and left 2 blocks behind. This seemed to tell the mother that if she kept the door and window closed, and didn't let any friends in, everything would be OK.

The law of conservation of momentum says that the total momentum of a system always remains constant.

So, every time the little girl found something new to do with her blocks, the mother figured out a new formula to help her keep track of them!

How is this story like the conservation of energy? Well, when scientists or engineers calculate the amount of energy in some system (the system could be anything — an electric motor, an air-conditioning system, or even our solar system), sometimes some of the energy leaves the system and sometimes some energy comes in from outside.

They must be careful to consider every possible source or consumer of energy in order to make their energy calculations balance correctly.

In fact, if scientists studying a particular system don't find that the total amount of energy is conserved, they "invent" a new form of energy that exactly makes up the difference! (This is the way that nuclear energy, chemical energy and electromagnetic energy were discovered.)

The new types of energy are then tested by other scientists, and those that survive all the tests become part of our broad concept of energy.

One thing about energy that is not like the little girl's blocks is that energy is not found in little blocks or chunks. In fact, we don't really know exactly what energy is. But, remember, we know that it can't be created or destroyed!

Momentum

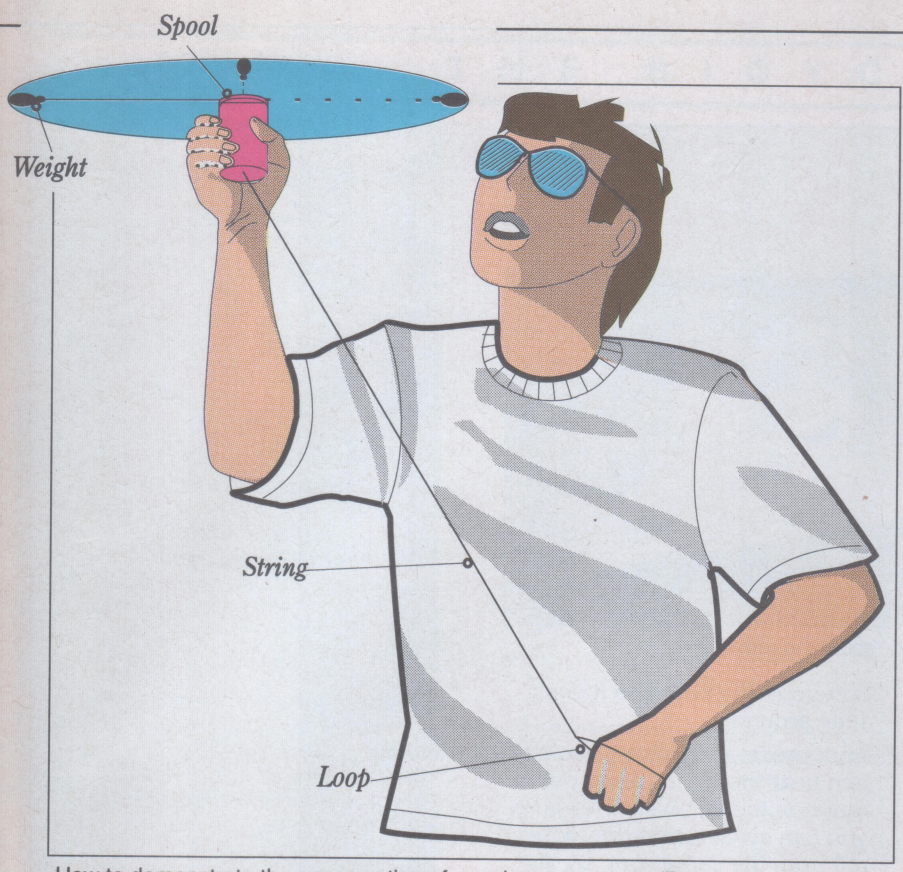
Kinetic energy, which you'll remember is the energy of motion, is closely related to *momentum*. The momentum of a moving object is defined as its mass times it velocity. Momentum, like energy, is also law-abiding. The law of *conservation of momentum* says that the total momentum of a system always remains constant.

Things that are moving in a circle — like a merry-go-round or a spinning wheel — possess *angular momentum*. It is calculated a little differently, but it also obeys the conservation law. We'll take a closer look at angular momentum through an experiment.

Let's Experiment!

The Conservation of Angular Momentum — You will need a thread spool or a short section of pipe about 4 centimeters (1.5 inches) long, a piece of string about 1.5 meters (5 feet) long, and some kind of weight. (Metal washers work well.)

1. Feed one end of the string through the spool or piece of pipe.



How to demonstrate the conservation of angular momentum. (Be careful! Don't release the string, and make sure no one is nearby!)

2. Tie the washers or other weights onto the other end of the string. Tie a loop in the opposite end of the string big enough fit over your hand.
3. Stand somewhere out in the open, where you won't hit anyone or anything when you swing the string. Hold the spool over your head in one hand and hold the loop at the other end of the string in the other hand, as shown in the drawing above.
4. Begin to swing the weight in a big circle, keeping it moving smoothly at the same speed. Notice the speed at which it's moving. Be careful! Do not release the string, and be sure no one is standing nearby!
5. Continue holding the spool at the same height and pull down on the end of the string. What happens to the weight's speed?

The angular momentum is found by multiplying the mass of the weight times the angular velocity (the rate of spin) times the length of the string squared. According to the conservation law, the angular momentum must remain the same. As the string gets shorter, the mass of the weight doesn't change. So, the weight has to speed up (increase its rate of spin) in order not to change the momentum of the system.

Something to think about: Where does the energy come from that keeps the weight in motion?

Work? Let Energy Do It!

Energy and work are also closely related. We usually think of "work" as physical activity involving our own muscles or machines. But the scientific definition of work is very specific. Work is done when a force acts over a certain distance.

The amount of work done is found by multiplying the force by the distance. Work is a form of energy in action and energy is always used when work is done.

The same units measure both work and energy. However, several different unit "names" are used by different countries, or even by different industries within the same country.

In the metric system, work and energy are both measured in newton-meters, which is named the joule (pronounced "jool") after a famous British scientist who did a lot of work with energy and heat. In the United States and Great Britain, the unit of foot-pound is often used. You might also see British thermal unit (Btu), erg, calorie and kilowatt-hour.

People are often concerned with how quickly a certain amount of work can be accomplished. The rate at which work is done is called power. Power is also measured in several different units, including joules per second, horsepower and watts. (The watt is most often used to define electrical power.)

Let's Experiment!

A Working Can — We will set up an incline using a board or a stiff piece of cardboard and a pile of books. We'll roll a can down the incline and measure how far it rolls past the edge of the incline.

Hold the can at the top of the inclined plane adjacent to the pencil mark.





Release the can, measure how far it rolls, and record the results.

Scientists have done a lot of experiments like this, and have found that how far the can rolls depends mostly on two things: how much energy it has when it leaves the incline and the type of surface it is rolling over.

The friction between the surface and the can eventually uses up the energy in the can's motion (by turning it into heat energy) and stops it.

Friction is the force that shows up when two things are rubbed together. Depending on the type of surface, there can be different amounts of friction. Motion is always easier when there is less friction.

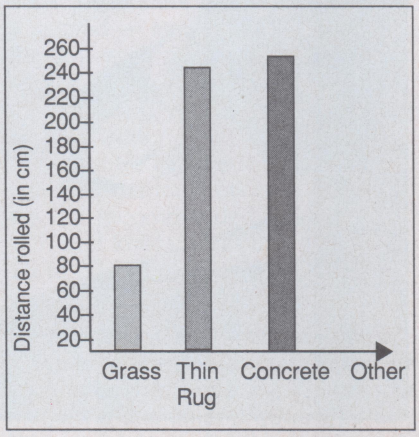
Friction is both useful and damaging. Car wheels couldn't grip the road without it. The friction between your shoe soles and the ground is what allows you to walk and run. (But it also causes your shoe soles to wear out.) Friction in machinery wastes energy and causes wear and tear.

The kinetic energy that the can gets from its roll comes from the force of gravity. This energy is used to do work in rolling over the surface.

This is similar to any rolling vehicle. Instead of gravity, a battery-powered toy car gets its energy from electrical/chemical energy stored in its batteries. A gasoline-powered automobile gets its energy from burning gasoline, which is derived from fossil fuel.

1. Prop the end of the board on a pile of books, so that it is about 8 centimeters (3 inches) above the floor. You might want to tape the bottom of the board so it can't slide around.
2. Mark the board with a pencil or pen near the top end and put a mark on the can also. This is so you can always start the can's roll from the same spot, by lining up the two marks.
3. Line up the mark on the can with the mark on the board and let the can go.
4. Measure how far the can rolls past the end of the board and record your measurement.
5. Repeat the experiment on several different surfaces (for example: wooden floor, linoleum, thin rug, shaggy rug, grass and sand).
6. Make a chart of your results, like the one shown below.

Do you think a heavier can would roll further on the same surfaces? Why? Try it and record your results.



How Do We Get Electrical Energy from Water?

Hydroelectric power stations transform the kinetic energy in falling water into electrical energy using water wheels called turbines.

Turbines have long axles and a number of metal blades. As the water runs over the blades of the turbine, it makes them turn. The turbines are connected to machines called generators, which produce the electricity. The figure at left shows a typical hydroelectric power station.

Generators make use of a discovery made by Michael Faraday back in the early 1800s. He found that electrical currents are generated in an electrical conductor (like a copper wire or other material that can carry electricity well) when the conductor is moved around in the field of a magnet.

The spinning turbines in a hydroelectric plant are attached to big coils of wire, which turn rapidly through magnetic fields. Electrical energy is then generated in the moving coils and carried off through big cables to our homes and businesses.

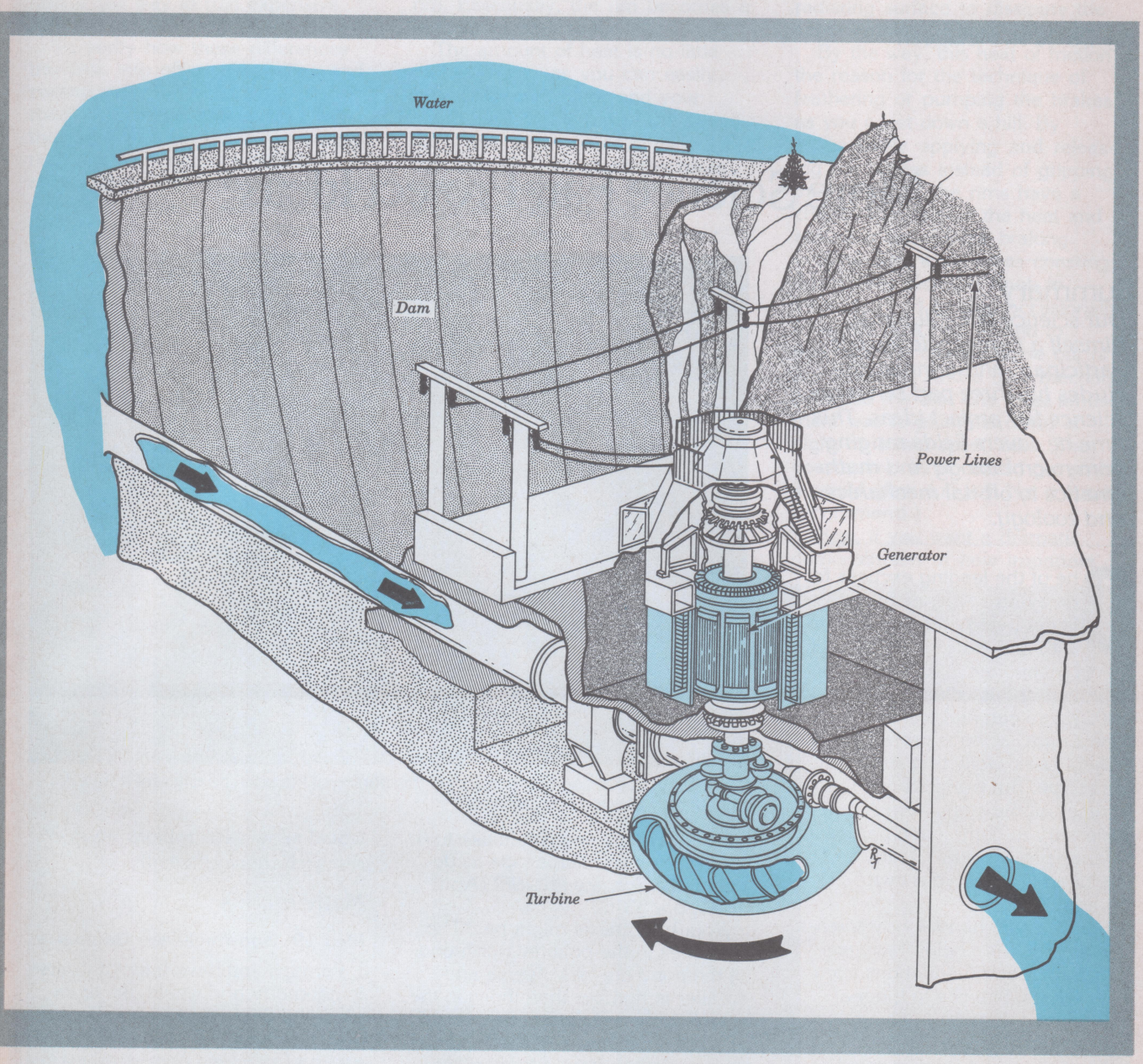
Other types of power stations use exactly the same principles to make electricity, except that the turbines are turned by strong jets of steam. The heat to make the steam usually comes from burning fossil fuels in a boiler or from a nuclear reactor.

Energy certainly goes through a lot of changes so that we can turn on a light or cook our food!

Energy and the Future

Will we run out of energy? Well, the scientific laws that control how much energy is available to us (called the laws of thermodynamics) tell us about something called entropy. Entropy has to do with the fact that the universe is moving toward a state — far, far into the future, fortunately — in which no energy is available for use.

Entropy means that things in nature have a built-in tendency to be jumbled or disordered. Eventually everything will become totally disordered and no energy will be us-



able. (Maybe you can use entropy as an excuse for your messy room!)

Why does entropy exist? Every time energy changes to a different form, some of it escapes into a disordered form that we can never use again. For example, we can't "unburn" a match or unscramble an egg, can we? In other words, the universe is "winding down." Will something eventually happen to wind it up again? No one knows!

Entropy is sort of mysterious and interesting to think about, but we do have other energy problems to worry about today. We have been lucky that energy from the sun was stored in Earth long ago as fossil fuels. That energy is easy for us to use right now, but it is possible that in the future we will use up all our coal, oil and natural gas resources.

We have learned that nature always conserves energy. The law of conservation of energy says that energy cannot be created or destroyed. But now **we** must learn to conserve as well.

Why not try keeping a record of your own energy use for a week? Look for ways to use your own "muscle energy" instead of electrical energy or other forms of energy that consume fossil fuels.

Scientists and engineers are always working on finding new energy sources. Who knows — perhaps you will be an "energy pioneer" of the future, discovering new ways to use our energy more efficiently? ✳

ABOUT THE AUTHOR

After teaching elementary school for two years, Carol Lewis went back to school for her engineering degree. She has since worked as an electrical engineer and an engineering editor for a major book publisher. She is now president of a small technical publishing company.

By David R. McQueen

More Science Fair Project Ideas

Summary

Our science fair columnist, himself a former science fair participant and winner, concludes his three-part series on science fair project ideas. This time he covers fields ranging from microbiology and mathematics to orbital mechanics and zoology.

One of the leading excuses for delaying a science fair project is not being able to come up with an idea.

As I mentioned in an earlier installment of this column (April 1992), you can find plenty of "snap-tight" science projects in project cookbooks that supply all the recipe. But using a book that outlines all the steps from A to Z necessary to complete a particular science project is not nearly as useful as devising your own project.

On the other hand, every scientist benefits from helpful suggestions and recommendations from co-workers. Science in the real world is not done in a vacuum nor from scratch.

Keep these thoughts in mind as you go through the project ideas that follow. If you didn't find any ideas in my previous two columns, maybe you'll find one here.

Microbiology

Idea 17: Microbiology of a Pond

Students often overlook project ideas which may be literally in their own backyards. One of the basic skills of a microbiologist involves the classification of microbes. Using a microscope from school and reference books from the library, identify the microscopic plants and animals from a pond near your house. Perhaps you would like to build your own microscope as described in *Science PROBE!* (April 1991, pp. 53-62).



Would the population of organisms in this portion of the pond be different from the population in a non-polluted area?

Your hypothesis might be: "The microbes in the polluted north end of the pond are less diverse and smaller in number than those in the unpolluted south end of the pond."

Always use caution when collecting specimens from a body of water. Use common sense and take along a friend.

Idea 18: A New Device for Moving Slides on a Microscope

Design a new or improved device to move a microscope slide around the stage. Look at the stages on microscopes at your school. Then do research in books to see what has been done.

Scientific supply catalogs would be a good source for your research. A project such as this would involve a study of the field of *ergonomics* (look up the meaning of this term). An improved design would allow a microbiologist to do research more efficiently.

Mathematics

Idea 19: Non-Euclidean Geometry

Perhaps you have taken a course in geometry and would like to explore the field. Most high school geometry courses are based around Euclidean geometry, involving concepts of point, line and plane.

You can design a science project around the development of a non-Euclidean set of theorems.

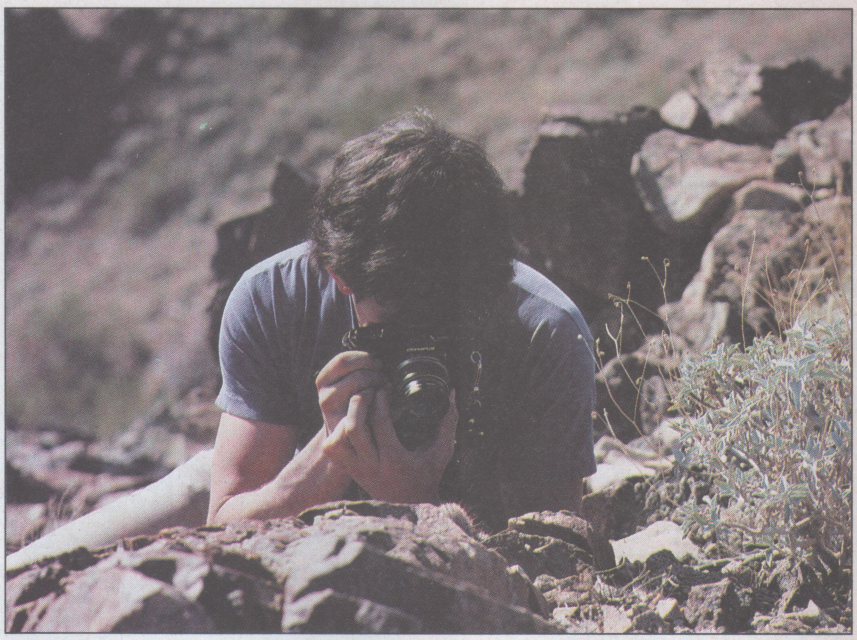
For starters, consider that a non-Euclidian triangle can have two 90-degree angles. To find out how, just look at the longitude lines on any globe. Although they are all perpendicular to the equator, they all intersect at the poles to form triangles on the surface of the globe.

Interested? Then visit your library and see what you can find. If you're into computer graphics, this might be the perfect project.

Idea 20: The Mathematics of Election Year Polls

Because this is a presidential election year, you've probably been hearing a lot about public opinion polls. What is the statistical basis of such polls? What is the mathematical significance of the "plus-or-minus 3%" figure that you often hear quoted? What controls the percentage of error in a poll?

If you enjoy working with computers, this project idea should be especially appealing. Perhaps you can write a program that will ask students at your school to enter such information as their age and gender along with a vote for the candidate of their choice. At the end of the day of voting, the program will then tabulate the results and, if you're clever enough, display a bar graph showing the distribution of voters for each candidate according to their age and gender.



Photography is an important part of any field research project.

Medicine and Health

Idea 21: Plants Used as Drugs

A major area of pharmaceutical research involves the development of drugs derived from plants. Before 1800, people called *herbalists* studied the use of plants as drugs. One such preparation made from the bark of a willow tree relieved the pain of headaches, sore muscles and aching joints.

What modern medicine does this sound like to you?

If you picked aspirin, you're right! In 1899, the salicylic acid of the tree bark was synthesized as acetylsalicylic acid, our modern aspirin.

What are the most common plants from which medicines are derived? Perhaps a high school, college or laboratory chemist can show you how to identify and extract a medicinal drug from a plant. If you grow a set of these plants under varying conditions, is the concentration of the chemical changed?

This project would be a good task for a summer institute or a science training program. Ask your science teacher about possibilities in your area. (See also Medicinal Plants in this issue.)

Idea 22: Survey of Fat and Caloric Intake by Family Units

Health research over the last 10 years has focused on the impact of diets high in fats and calories. This project idea involves researching the amount of fat and calories consumed by a family unit.

What does **your** family eat each day? What quantity of fat and how many calories are found in this diet?

Publications on nutrition available at a public library and from local offices of the Department of Agriculture will allow you to assign the number of calories and grams of fat in known amounts of each food item.

Next, expand your survey by asking your neighbors, friends and relatives to participate. Start with about 10 family units.

How would you design a survey form to find out what each person has eaten each day? Is there a way to do this project without asking questions of individual family members? Could you reduce the paperwork by performing a weekly inventory of each family's refrigerator and pantry? This shortcut assumes that most people eat most meals at home. How accurate do you think this is in your research group?

Your study should also involve references to medical research on the effects of high fat and high calorie diets. What are the health effects of a low-fat diet? The rules of the International Science and Engineering Fair (ISEF) should be followed even when human subjects are involved in what may seem just a simple survey. Depending on how you design the project, you may need a consent form for each person. Be sure to check the rules *before* you begin the project. Ask your teacher for advice if you are unsure about the rules.

Physics

Idea 23: Orbital Mechanics of Satellites Around Mars

If you are good at math and interested in space, then you might excel in a theoretical study such as this one revolving around orbital mechanics (no pun intended!).

What physics controls the orbit of an artificial satellite around a planet? Library research will reveal the equations needed to do such a study. Set up your initial conditions, such as the mass of the object to be placed in orbit, and formulate a mathematical model of the launch, orbital insertion and life of the satellite. Making a solar system model out of wooden dowels, Styrofoam balls and string would add a nice touch to your project display.

If you enjoy computer science, this project will go much faster if you write a program to assist your research. If you're good at programming, you can even develop a program to illustrate the orbital path of the satellite.

Idea 24: The Biophysics of Cat Locomotion

How does a cat walk? At first glance, this may seem a trivial question. But consider it from a physicist's viewpoint.

How many watts of power does it require for a cat to run 100 meters? What are the forces that act on the joints in a cat's leg? For example, how many dynes/square centimeter of stress act on the knees of a cat while it is running? Look at the problem from the viewpoint of building a model of a walking cat. Should the limbs be made of wood, plastic or metal? How much power would be needed from an engine to move a robot cat that weighs 3 kilograms?

Exploring these questions could lead to an enjoyable and award-winning project.

Zoology

Idea 25: Comparison of Rabies Rates Between Urban and Wild Animals

Rabies is an acute, often fatal, viral infection which affects wolves, cats, dogs and other mammals. This project would involve no contact with actual animals, just the gathering of data on the numbers of reported cases in your area. One hypothesis you might test would read: "Cases of rabies are higher in urban areas than rural."

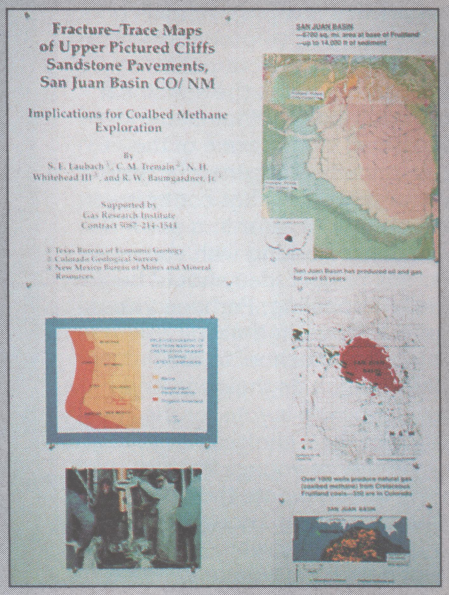
Approach this project as a survey. Contact veterinarians and ask about how many cases of rabies they see each year. Then contact the nearest office of your state's Fish and Wildlife Commission and ask about rural areas. Ask professionals that you interview for published lists of detected diseases in wild vs. tame animals. Use this data to compare and contrast the disease within these diverse populations of animals.

Like any project that involves numbers and statistics, this is a good topic for a computerized spreadsheet. Ask your teacher if your school has a computer with spreadsheet software. If so, you can make nice graphs of your survey results. (Also, refer to "Basic Statistics" in the April 1992 issue of *Science PROBE!*)

Science Fair Projects for Professional Scientists

What do the annual meetings of the Geological Society of America and the Society of Environmental Toxicology and Chemistry have in common? Like many other scientific and engineering societies, both have formal presentations of scientific papers and informal poster sessions.

A poster session is shown in the photograph at right. Does it look like a science fair to you? It does to me. The same skills that you would learn in doing a science fair project can be carried over to a poster session. This style of presenting a scientific report has become very popular and is now as accepted as the more traditional method of making an oral presentation of a paper.



Poster from the session David McQueen attended at the 1990 Annual Meeting of the Geological Society of America, where he presented an oral paper.

Idea 26: Animal Study at a University Laboratory

Laboratory animals are used routinely in zoological research. They include rats, mice, rabbits, chickens and even earthworms. The ISEF very carefully regulates student projects that use animals. Therefore, my advice is to call a local university and see if a biology or zoology professor will allow you to participate in part of an ongoing animal research project in the professor's lab.

This kind of science fair project requires more supervision than most of the others I've described in this column. Therefore, your parents and teachers should help you establish the contact with the university.

Science Fair Rules

As I have often reminded you in this column, most major science fairs follow the rules devised for the annual International Science and Engineering Fair. Therefore it's important for you to be familiar with these rules as early as possible. You can receive a copy of the ISEF rules by writing:

Science Service
1719 N Street, N.W.
Washington, D.C. 20036

A single copy of ISEF rules will be sent free. If your teacher wants to order more, the cost is 75 cents each.

Summing Up

My goal in writing this and the previous two columns has been to give you an idea of the many kinds of science fair projects just waiting to be explored.

How nice it will be if one of these suggestions catches your eye, and you turn it into a project! If the ideas listed here lead you to think of another project, all the better. What's important is to find an idea you like and transform it into a quality science fair project. ✶

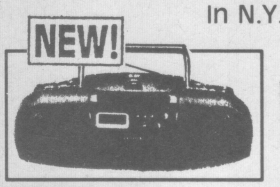
ABOUT THE AUTHOR

David R. McQueen is a professional geologist and science educator who received awards at two International Science Fairs when he was a high school student. McQueen has served as both a high-school science teacher and a college professor. He has also judged science fairs in several states.

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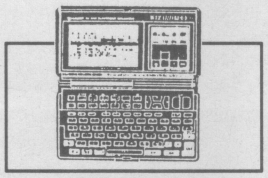
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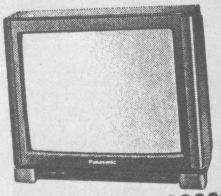
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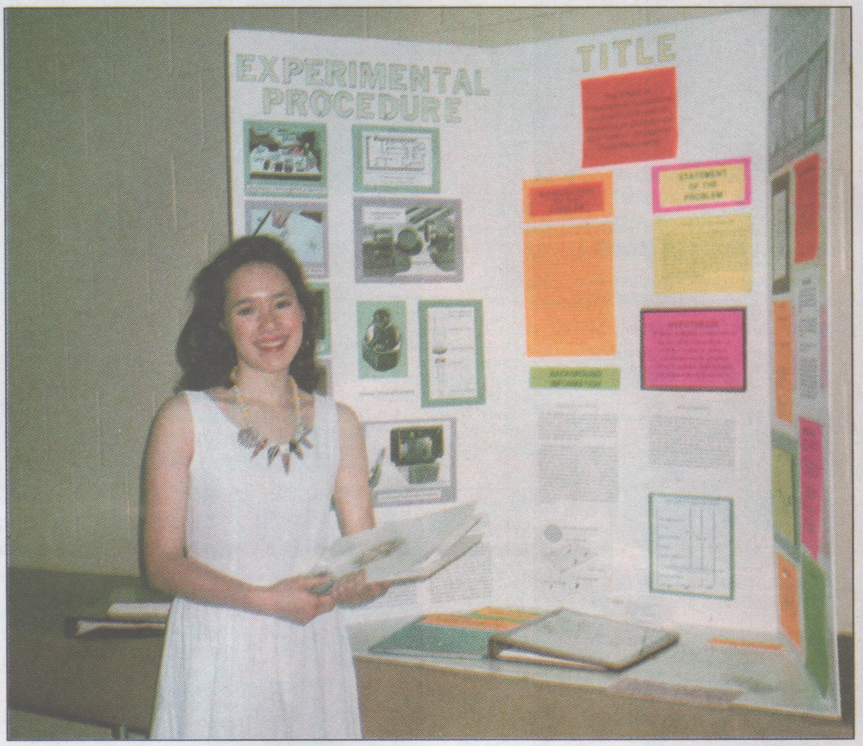
SP1192

By Monica Crane

The Effect of Tropospheric Conditions on UV-B

Summary

Ultraviolet-B radiation wavelengths between 280 and 320 nanometers (nm) cause erythema in humans, which can lead ultimately to skin cancers and cataracts. To test the hypothesis that absorbing and scattering agents such as clouds have a drastic effect on direct UV-B from reaching the Earth's surface, Monica Crane recorded UV-B daily with a UV-B radiometer she constructed. The resulting data supported her hypothesis



Monica Crane with the results of her science fair project.

Solar ultraviolet (UV) radiation has a strong environmental role, especially in relation to the ozonosphere — the ozone layer, an envelope of atmospheric gas.

Many scientists believe that this life-protecting stratospheric layer, which shields the Earth from excessive solar radiation, is being reduced by chlorine atoms from chlorofluorocarbons (CFCs).

Therefore, a prime reason for concern about ozone depletion is the threat of biological damage because of increased solar UV radiation. UV rays can ionize or knock electrons out of atoms and molecules, causing harm to body tissues, living cells and DNA (deoxyribonucleic acid). UV causes erythema or sunburn in humans, which can lead to skin cancers.

UV radiation, ranging from 200 to 400 nanometers (nm), is classified into three categories related to their transmission qualities in the Earth's biosphere. (See Figure 1 on the opposite page.)

The non-harmful UV-A (320-400 nm), occupies a region of relatively low absorption by ozone and is not biologically threatening. But UV-B (280-320 nm) is merely attenuated by the ozone layer, and even so, not completely. Therefore, the UV-B is the spectrum of radiation that could affect humans negatively, as the ozone layer is depleted.

Luckily, the shortest and most damaging wavelengths of UV radiation, UV-C (200-280 nm), are unable to penetrate to the surface because of stratospheric ozone absorption. Nevertheless, scientific studies of UV-B need to define the role of tropospheric conditions on UV-B, in order to more fully understand the atmospheric process.

Studying the Transmission of UV-B in the Ozone Layer

Within the last 5 years, global models have predicted long-term ozone decreases. The impact of these decreases is not certain. Presently scientists lack a substantial network to observe and collect data on UV-B radiation, and information demonstrating a definite correlation between air quality and UV-B penetration.

In addition to simple UV readings, the role of cloudiness and other environmental factors influencing the transmission of ultraviolet in the troposphere needs to be addressed. Ultraviolet irradiance may in fact depend on systematic latitudinal differences in cloud cover, aerosols and localized sources of air pollution.

This hypothesis was formulated for the study: If direct radiation measurements on the relative magnitude of UV-B are taken, a definite correlation can be graphed between ambient light intensity and ultraviolet-B penetration.

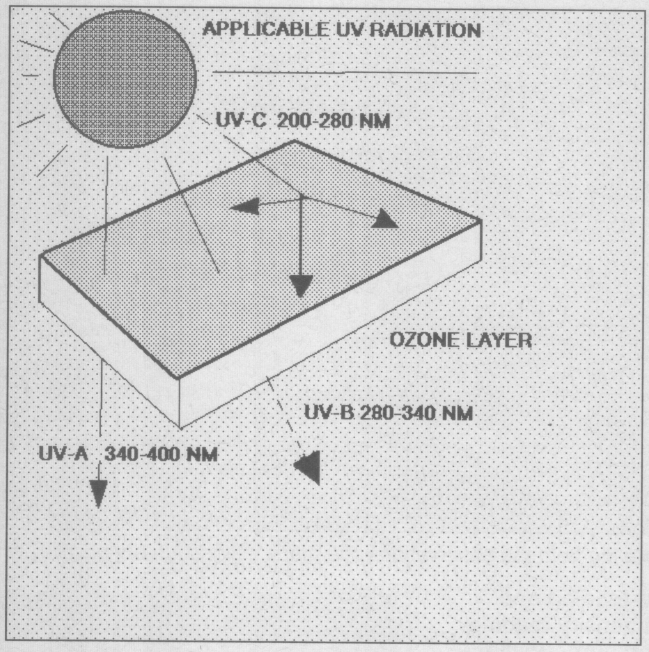
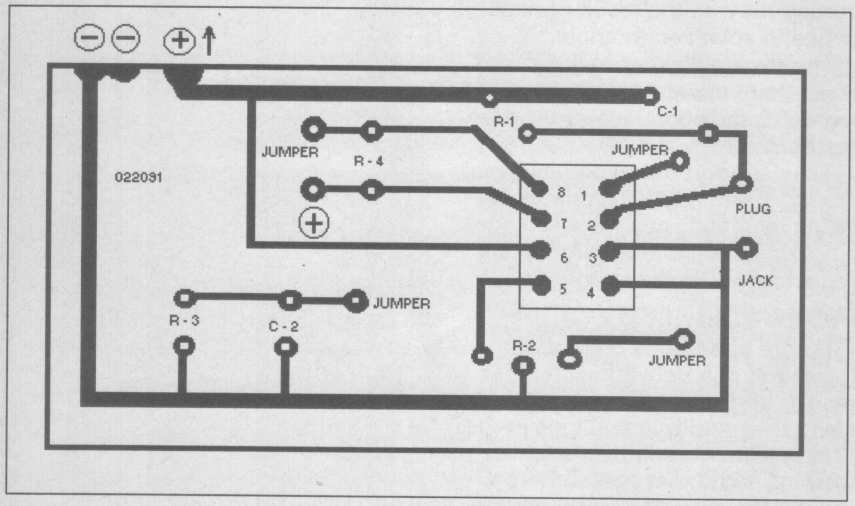


Figure 1 (left). From Monica's report — an illustration of the ultraviolet radiation bands studied in her project.

Figure 2 (below). Monica designed this printed circuit board, which used a Texas Instruments TLC271 integrated circuit.



Design and Construction of the UV-B Radiometer

An original printed circuit (PC) board was designed and built around a Texas Instruments miniature amplifier [integrated circuit]. (See Figure 2.)

After all components had been gathered, a copper-plated PC board was cut to fit the dimensions of the selected housing. The board was cleaned, the circuit was traced in with a resist ink pen, and the board etched in the usual manner. Recommended safety precautions include ventilation, skin protection and safety glasses.

Following the etching process, all materials were thoroughly rinsed in water and the resist ink was removed from the PC board with solvent.

Holes for component leads were drilled with a small (#61) drill and components soldered in place. All components were tested with a volt-ohm meter.

At this point a plan for fitting all miscellaneous components in the housing was developed, resulting in the internal battery placement at one end, digital voltmeter plugs, collimator plug, and power switch being on top of the unit. Next, all lead wires were then soldered on, and the board was loosely placed in the housing.

Note: The TLC271 operational amplifier has its own IC-socket and was inserted as a last step with a special tool to protect against damage (from static electricity).

Collimator Construction

A 12.5 millimeter-diameter optical filter, transmitting 304 nm radiation with a band pass of 10 nm, was employed to pass only a selected range of ultraviolet light to the radiometer's detector circuitry.

The next stage, a gallium phosphide diode, was used as the radiometer's UV-level detector and to provide a small voltage that is amplified in the amplifier section.

Both the diode and filter were assembled in a light-tight brass union coupling. First, a two-conductor phone plug was inserted into a brass cap, which screws onto one end of the union. I had the cap bored and tapped to fit the plug's threads. Rubber o-rings provide a light-tight seal all around.

The cathode lead of the diode was soldered to the terminal that is common to the tip of the plug. The filter, also protected by a pair of o-rings, was then installed in the second end cap — securely tightened, yet not so much to cause stress or breakage.

The collimator tube was soldered onto the brass conical end cap opening to reduce the detector field view from 10 degrees to a level of 4 degrees.

Ultraviolet Reading Procedures

The brass collimator unit and digital voltmeter are connected to the operational-amplifier housing unit. When collecting data, the radiometer's potentiometer is adjusted to zero while the collimator end is blocked.

The measurements were taken daily at solar noon. Computations were made with the absolute spectral irradiance at 304 nm in terms of watts per square meter.

The readings were recorded in volts, and the data was used to calculate the direct UV-B in the units of watts per square meter per nanometer.

Readings of the ambient light intensity in footcandles of light were also taken and recorded from a standard Spectra footcandle meter. Ultraviolet readings as related to temperature, humidity, barometric pressure and other atmospheric

conditions were assembled in the data log.

Results of the Study

The dataset in Table 1 was obtained from March 30 to April 7, 1991, by a gallium phosphide diode UV-B radiometer, located in Creve Coeur, Missouri (38.37 N, 90.72 W), at an elevation of 39 meters (126 feet).

The daily flux of UV-B radiation was recorded, and the average net flux of UV-B radiation over the given time period, is shown in Table 1. The data from direct UV-B radiation was used to determine what effect the absorbing and scattering agents, such as clouds and haze, have in the atmosphere.

The raw data exists as daily observations at-or-approximately 12:30 p.m. Central Standard Time (CST). The temperature, barometric pressure, cloud levels, weather conditions, and footcandles of light were taken and recorded at this time.

The footcandle measurement served as an indicator of cloud cover and haze. The data displayed a direct relationship between the intensity, cloud cover and haze, and the UV-B levels.

Raw voltages were taken and inserted into the UV-irradiance formula. The data was then graphed as a function of local time in St. Louis, along with the light intensity. The white graph is the light intensity in footcandle (ftc) units. The gray is the UV-B reading in milliwatts per square meter per nanometer. A histogram accommodated both light intensity and UV-B levels on the same graph, displaying the units of UV-B irradiance from watts per square meter per nanometer to milliwatts per square meter per nanometer.

Analyzing the Data

The resulting graph was a fairly steady irradiance and ftc change with one major peak and dip. The graph had a definite maximum and minimum.

The maximum level of UV-B irradiance was on April 5, 1991, with weather recorded as clear, cloudless, sunny skies. The footcandle level peak corresponded directly to the peak in the UV-B level.

Similarly, the extremely thick cloud cover present the day before on April 4, 1991, resulted in both an extremely low UV-B reading and footcandle or light intensity reading.

Minor errors in the numerical accuracy may be the result of negligence to solar zenith angle.

The results illustrated the important role of cloud cover in moderating UV-B radiation levels at the terrestrial level.

They support the hypothesis that, next to stratospheric ozone, scattering by clouds and haze provides a major substantial shield limiting terrestrial UV-B radiation levels.

UV-B RADIOMETER - DATA LOG BOOK

DATE	TIME	WEATHER	Barometric PRESSURE	TEMPERATURE	FOOTCANDLES	VOLTAGE	DIRECT UV-B (*)
3/30/91	12:36	no clouds Sunny (not strong though)	30.10	60°F	11000	3.70	.0034079 .0031897 .0027982
3/31/91	12:30	partly sunny (some clouds)	30.13	70.0°F	16000	7.60	.0069997 .0065517 .005781
4/01/91	12:31	clear (hazy) sunny though	30.25	68.0°F	12,500	4.10	.0037761 .0035345 .0030896
4/02/91	12:30	partly sunny	30.25	67.0°F	15,000	6.20	.0057103 .0058468 .0046721
4/03/91	12:30	cloudy	31.14	60°F	4800	1.71	.0015749 .0014741 .0012886
4/04/91	12:30	heavy overcast	29.72	61°F	800	.14	.0012894 .0012069 .0001055
4/05/91	12:30	very sunny no clouds!	29.85	72°F	25,000	12.10	.011149 .010467 .009118)

SAINT LOUIS, MISSOURI, U.S.A. - 126 Feet Above Sea Level LAT: 38.37 North LONG: 90.72 West

* Direct UV-B is in watts / metre squared / nanometre

Table 1. Monica's data log from the observations she made in Missouri during 1991.

Future Study of UV

Future operations consist of the formation of a network with other researchers or interested individuals to take multiple readings in the St. Louis metropolitan area. Networking with other researchers around the nation to begin the creation of a permanent record of UV penetration for the United States over several seasons or years is the ultimate goal.

A compilation of the UV-B information to provide researchers with a document from which to base their own future studies is also planned.

Acknowledgments

My father; Anthony Kardis, Mr. Harpel and Mr. Miller of Ladue Horton Watkins High School; Pamela Lambright at Eltec Instruments, Inc.; Dr. John E. Frederick of the Department of Geophysical Sciences at the University of Chicago; Marshall Industries, agent for Texas Instruments; the staff of George Engelmann Institute; and Forrest M. Mims III. ✳

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ABOUT THE AUTHOR

Monica Crane presented this Science Fair project at the 44th Greater St. Louis Science Fair in 1991. She won first place in the honors division and was interviewed on the CBS television affiliate there. Crane's project helped her get a summer job as a research assistant at the University of Missouri. She is planning to enter a pre-med program in the fall of 1992.

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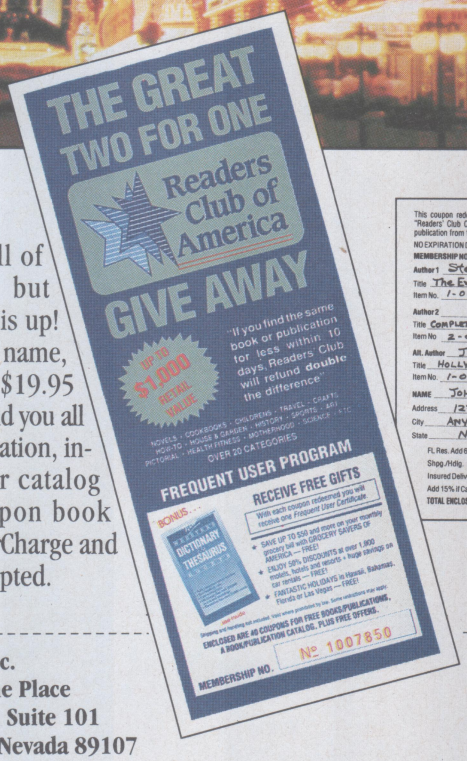
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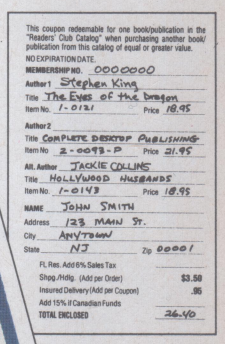
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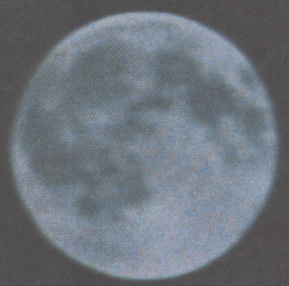
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TRACKING THE



This remarkable photograph of the full Moon rising above the Earth's horizon shows, from the bottom, the clouds of the troposphere (pale blue and white); the cloud-free lower stratosphere (blue); and the ozone layer (violet). The photograph was made from Skylab 3 in 1972.

OZONE LAYER

An Amateur Scientist Explains the Ozone Layer and Its Effect on Ultraviolet Radiation from the Sun

By Forrest M. Mims, III

Summary

Over the past decade there has been a measurable decline *in the amount of ozone drifting in the stratosphere over high northern and southern latitudes. Conversely, there has been an* increase *in ozone near the ground. What effect do these changes have on the amount of solar ultraviolet reaching the Earth's surface? The editor of* Science PROBE! *has measured ultraviolet radiation and the thickness of the ozone layer almost daily since 1989. Here is his report.*



Sprinkled throughout the atmosphere are pale blue molecules of a toxic gas that are essential to the existence of most life on Earth. This gas is ozone.

Ozone is toxic because it is highly reactive. This is why it can sterilize drinking water, eliminate odors, decompose rubber and bleach colors. The amount of ozone in the air at the Earth's surface is usually too low for these effects to be observed. However, high concentrations of various air pollutants and sunlight can increase ozone levels near the ground from tens of molecules per billion molecules of air (ppb) to a few hundred ppb. These levels of ozone can damage plants, irritate eyes, inflame mucous membranes and impair the performance of athletes.

Ozone is essential to life because it shields the Earth from the damaging, even lethal, ultraviolet (UV) radiation emitted by the Sun. This filtering ability is particularly remarkable when examined in the context of the relative scarcity of ozone molecules. For every billion molecules in the atmosphere, only about 300 are ozone.

Assume you could poke an open tube through the entire atmosphere over your head and bring all the ozone molecules in the tube down to the surface. If they were then subjected to the same temperature and atmospheric pressure (standard temperature and pressure) as you are, they would form a layer only about 3-millimeters thin.

Although they may be formed in many different ways, all the ozone molecules in the stratosphere are identical. An oxygen molecule (O_2) is composed of two oxygen atoms (O). UV radiation can split an O_2 molecule and leave behind two free O atoms. Various chemical reactions leave O atoms as a by-product. In either case, a free O atom can merge with an O_2 molecule to form triatomic oxygen (O_3), more commonly known as ozone.

The Two Ozone Layers

The phrase "ozone layer" generally refers to the relatively high concentration of ozone in the stratosphere, the layer of dry air about 15 to 35 kilometers (9 to 22 miles) above the Earth's surface. However, about 10% of the total ozone above most places on Earth is found in the troposphere, the lowest portion of the atmosphere. The troposphere contains 90% of the atmosphere and nearly all of the atmosphere's water vapor. Storms form in the troposphere and usually stay there. But the tops of especially virulent thunderstorms sometimes poke into the lower stratosphere.

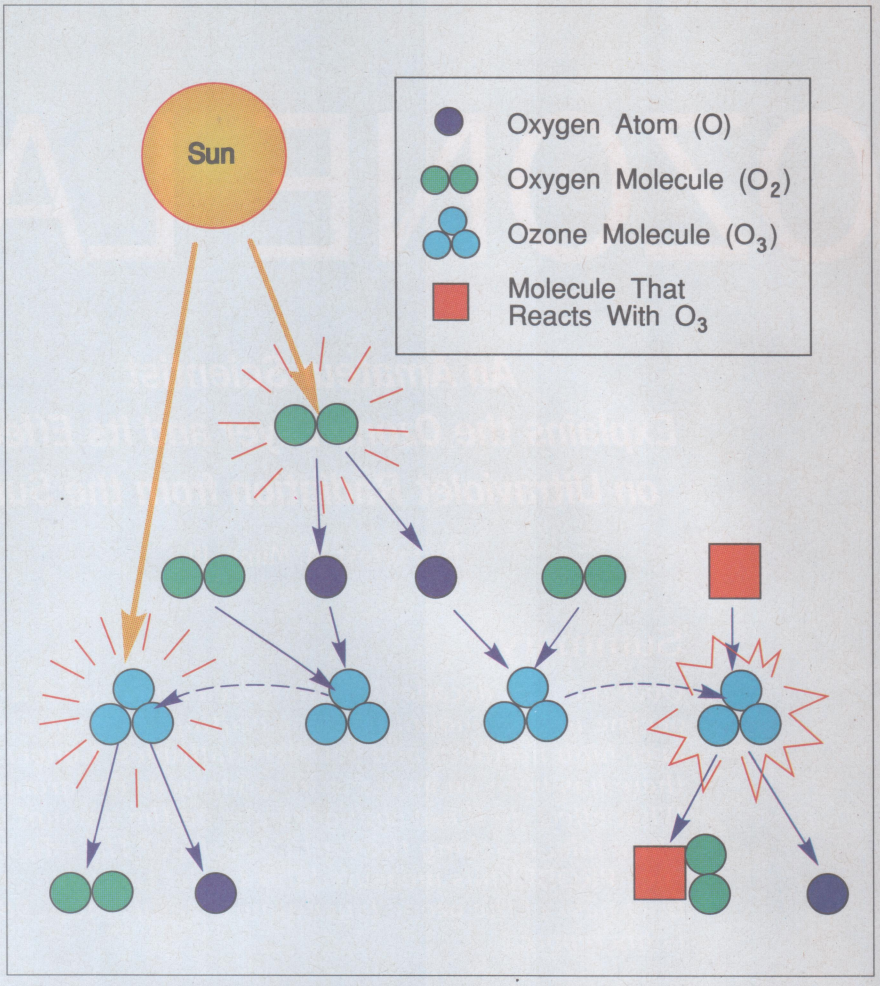


Figure 1. A simplified view of how ozone molecules can be formed and destroyed.

The tropopause, the border between the troposphere and the stratosphere, ranges from about 10 to 15 km (6 to 9 mi.) above the surface. The heat of summer increases the altitude of the tropopause; the altitude is reduced in winter. Generally, when the tropopause is low, the amount of stratospheric ozone is high; when the tropopause is high, the amount of stratospheric ozone is reduced.

Tropospheric Ozone

The ozone between the surface and the troposphere forms only a fraction of the total amount of ozone over most locations. Nevertheless, it absorbs solar UV more efficiently than an equal amount of stratospheric ozone. This occurs because scattering caused by dust and aerosols increases the distance that rays of sunlight travel on their way to the surface.

In spite of this benefit, tropospheric ozone is often referred to as "bad" ozone because of its adverse effects on people and plants in high concentrations. If the same ozone were somehow to drift up into the stratosphere, it would be referred to as "good" ozone.

Forming and Destroying Tropospheric Ozone

Though only 10% of the ozone is found in the troposphere, there are many ways it can be produced there. Some is formed by lightning and by UV radiation from the Sun. Most is formed by chemical reactions that take place in the presence of sunlight.

One such reaction is the conversion of nitrogen dioxide (NO_2) into nitrogen oxide (NO) in the presence of solar UV. The O atom left over from this reaction combines with an O_2 molecule to form an ozone molecule. Various other gases in the atmosphere can combine with NO to form more NO_2, which then can cause a build-up of

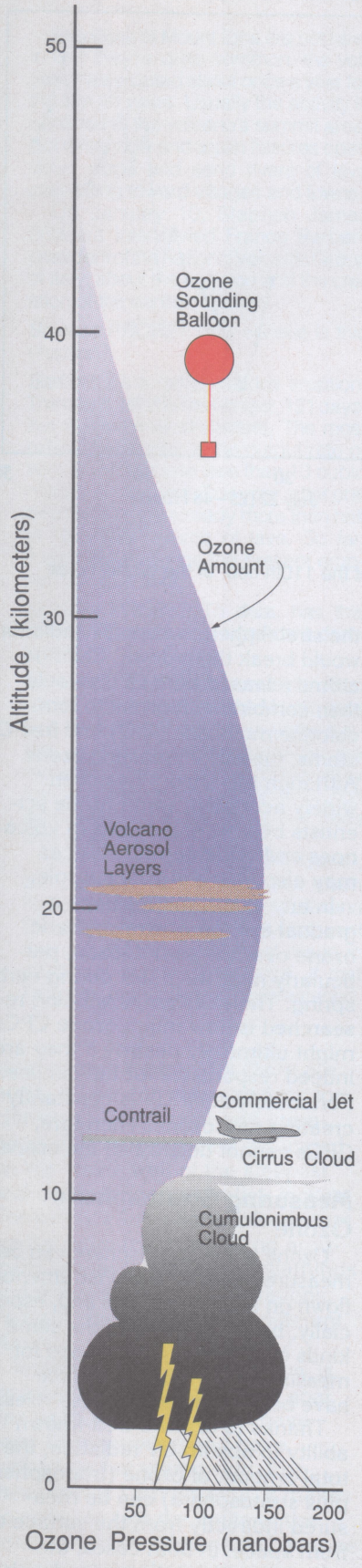


Figure 2. How ozone is distributed in the atmosphere.

ozone. Gaseous organic chemicals, in the presence of nitrogen oxides and sunlight, can also contribute to ozone production.

The same photochemistry that forms ozone can also destroy it. Indeed, some photochemical processes in the atmosphere are called "do-nothing" reactions since they destroy as much ozone as they create. UV radiation leaking through the ozone high in the stratosphere can also create and destroy ozone in the troposphere.

Measuring Tropospheric Ozone

There are several ways to measure tropospheric ozone. Because ozone is a strong oxidizer, it changes the color of some chemical compounds and solutions. For example, paper soaked in a mixture of starch and potassium iodide will change color when exposed to ozone.

The reaction of ozone with various chemicals, gases and even some lubricating oils causes a faint luminescence, which can be detected by a sensitive photomultiplier tube. Detection systems such as this are known as chemiluminescence detectors.

Because ozone absorbs UV radiation so effectively, many kinds of ozone detectors incorporate a UV lamp and a detector. Air is passed through a chamber, and any attenuation of the UV is assumed to have been caused by ozone. A problem with this method is that attenuation can also be caused by dust.

Therefore, it's common practice to use two chambers, one of which receives air from which any ozone has been scrubbed. Alternatively, scrubbed and unscrubbed air can be passed in sequence through the same chamber. Either way, the error caused by dust and other contaminants in the ozone-free sample can then be determined by subtraction.

Sulfur dioxide and other chemicals can interfere with the chemical and UV detection of ozone. When scientists at the Montsouris observatory near Paris became aware of this problem in 1905, they built a second chemical ozone detector. The air inlet for the new detector was fitted with a 4-meter (13 feet) hose of natural rubber, which completely reduced the O_3 passing through it to O_2. In this way any errors in the original detector caused by gases other than ozone could be eliminated.

Several times, my son, Eric, and I have measured the amount of tropospheric ozone between the bottom and top of mountains in New Mexico. We do this by measuring the total amount of ozone in a column through the atmosphere with a UV-sensitive instrument that is pointed at the Sun.

One of us goes to the top of a mountain while the other stays at the base. We then make a series of observations at prearranged times. Later, we subtract the ozone measured at the mountain top from the measurements made at the base to determine the amount of ozone in between.

So far our results (a few Dobson units per vertical kilometer; see Figure 5) have agreed with measurements made from balloons by the National Oceanic and Atmospheric Administration (NOAA).

Tropospheric Ozone Cycles

The amount of ozone above any given spot of Earth is rarely constant. Consider the diurnal (daily) ozone cycle over Albuquerque, New Mexico.

Early on a July morning at the base of the Sandia Mountain aerial tramway just northeast of the city, the ground-level ozone might have a concentration of, say, 20 to 30 ppb.

As the Sun rises high in the sky, photochemical ozone production increases (especially when the wind is from the southwest), because the clean mountain air is spiked with nitrogen oxides and hydrocarbons from automobile exhaust. Although little or no photochemical smog may be visible, the ozone level might reach 40 to 60 ppb by late afternoon.

As the Sun sinks behind the volcano cinder cones west of Albuquerque, the ozone level also falls. Late that evening, the ozone returns to its normal "background" level of 20 to 30 ppb.

Tropospheric Ozone Trends and Effects

The ozone measured at the ground near Paris, France, from 1876-86 was only around 30 to 50% of what is usual in unpolluted areas today. The increase since then is generally believed to be because of human activities. At least two-thirds of the nitrogen oxides are believed to come from the burning of fossil fuels, wood, forests and agricultural wastes. Nitrogen oxides are also produced naturally by lightning, forest fires and soil. Organic chemicals, such as methane and hydrocar-



bons, can be by-products of plants, animals and human activity.

It's interesting to compare the amount of ozone in a vertical column of air adjacent to a mountain with that over a city. In the summer of 1989, Eric and I measured 5.8 DU of ozone between the base and the crest of Sandia Mountain in New Mexico, an altitude difference of 1,164 meters (3,819 feet). A few weeks earlier I measured about 5 DU of ozone between the street-level plaza and the observation deck 420 meters (1,377 feet) atop the 110th floor of the World Trade Center in New York City.

A government scientist in New York City who makes ozone measurements at fixed sites told me that ozone levels can be much higher in the air a hundred meters above the streets of New York City and in the surrounding regions than near street level in the city. Apparently the high number of air pollutants, people, rubber tires and the like suppress ozone concentrations at street level.

When California forced a significant reduction of hydrocarbon emissions from automobiles, the ozone in downtown Los Angeles fell. Ozone levels downwind, however, continued to rise, even though traffic was lower. The scientists who puzzled over this dilemma noticed that there is considerably more vegetation downwind from the central city. They concluded that ozone is reduced only when both hydrocarbons **and** nitrogen oxides are reduced.

The relationship of trees and ozone is particularly interesting. Too much ozone can damage or even kill trees. Ironically, hydrocarbons emitted by trees participate in chemical reactions that produce ozone. Several years ago William Chameides of the Georgia Institute of Technology studied satellite images of Atlanta and found that 57% of the city was wooded.

He and his co-workers concluded that Atlanta's trees emitted at least as many hydrocarbons as the city's cars, trucks, buses and factories.

Stratospheric Ozone

Most references to the ozone layer mean the ozone found in the stratosphere. There it forms a vaporous shield that protects life on Earth from the lethal effects of the Sun's UV radiation. If you've flown the Concorde, then you have probably traveled through the bottom of the stratospheric ozone layer.

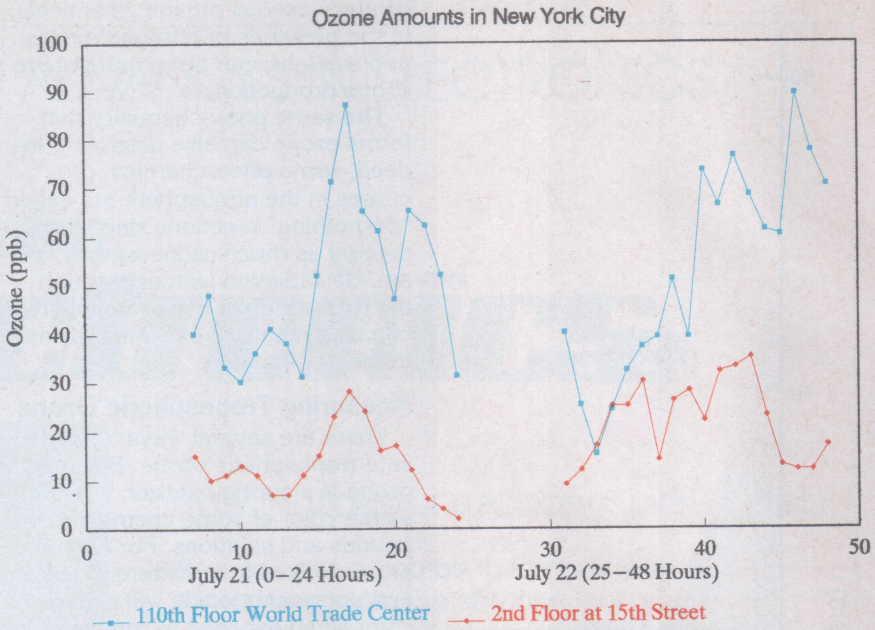


Figure 3. Ozone levels near the ground and at the 110th floor of the World Trade Center in New York City, July 21-22, 1989.

Forming and Destroying Stratospheric Ozone

Ozone in the stratosphere is formed by a natural photochemical process when UV radiation from the Sun splits molecules of oxygen into the two oxygen atoms from which they are formed. The free O atoms soon react with O_2 molecules to form O_3.

This process works both ways. The O_3 molecules that are struck by UV radiation split back to an O_2 molecule and a free O atom. These free O atoms can then merge with O_2 molecules to re-form O_3 molecules.

Ozone molecules that drift lower down in the stratosphere are protected from the destructive effects of UV radiation by the overlying blanket of ozone molecules. These molecules form what is commonly known as the *ozone layer.*

But even molecules of ozone deep in the ozone layer are not entirely safe, for they can be destroyed by reactions involving sunlight and oxides of nitrogen, hydrogen, chlorine and bromine. Although all these chemicals can arise from natural sources, manufactured chlorofluorocarbons (CFCs) have been of concern since 1970 when James E. Lovelock detected their presence in air.

In 1974, Sherwood Rowland and Mario Molina theorized that CFC molecules could eventually drift into the stratosphere, where UV radiation would break them down. Chlorine atoms released from CFCs would then combine with ozone to form chlorine monoxide (ClO) and free O atoms, thereby eliminating ozone. Although this theory has been widely accepted, some ozone scientists believe chlorine from volcanoes and other natural sources may also play a significant role.

In any event, there's been a gradual erosion of stratospheric ozone over the past decade, particularly near the poles during early spring. The question now being researched is how much ozone CFCs might ultimately destroy if they are indeed responsible for the decline. Fortunately solar UV is constantly creating new ozone. Therefore, CFCs cannot destroy all the ozone.

Measuring Stratospheric Ozone

Ozone in the stratosphere can be measured directly with instruments flown on aircraft, rockets and, especially, balloons. Many of the same kinds of sensing systems used for measuring ozone at the surface have been modified for these roles.

Thanks to ozone's well-known ability to absorb UV radiation, the total amount of ozone (troposphere plus stratosphere) can be measured indirectly from the surface or from space. In both cases, the ozone amount is determined with the help of an equation that considers the ratio of the intensity of two or more UV wavelengths and the

absorption of UV by ozone at those wavelengths.

Several kinds of optical instruments have been developed for measuring ozone from the ground, including the Dobson spectrophotometer and various instruments that use filters or diffraction gratings to measure narrow bands of UV.

The Dobson spectrophotometer forms the key link in the world-wide, ground-based ozone monitoring network. Invented in the late 1920s by G.M.B. Dobson, this instrument divides sunlight into a spectrum with a prism and measures the ratio of two UV wavelengths about 20 nanometers (nm) apart. Dust and aerosols can cause errors in ozone observations by scattering one wavelength more than another. Dobson observations are usually made at 2 pairs of wavelengths to cancel out this error.

The Dobson instrument is expensive, nearly 2 meters (6 ft) long and heavy — around 40 kilograms (85 pounds). Because it measures only the **ratio** of two or more UV signals, it provides no information about the amount of solar UV.

The Brewer ozonometer uses a diffraction grating to separate the Sun's ultraviolet wavelengths. This expensive instrument is smaller than the Dobson and well-suited for automated data-taking. It also measures sulfur dioxide, a gas that is emitted by many volcanoes and some industries. Sulfur dioxide interferes with ozone measurements. Some scientists believe that the Brewer measures ozone with higher precision than the Dobson. Indeed, Canada is now in the process of switching from Dobsons to Brewers.

HOW MUCH OZONE?

The average amount of ozone in a column through the atmosphere will form a layer 3-millimeters thick when subjected to the temperature and pressure at the surface. The amount of ozone in such a column is usually specified in thousandths of a centimeter. Therefore, a 3-mm amount of ozone in a column through the atmosphere is usually expressed as 300 milli-atmosphere-centimeter or 300 m-atm-cm.

A single m-atm-cm of ozone is known as a Dobson unit or DU after G.M.B. Dobson, who invented the spectrophotometer that is still used today to measure the total amount of ozone in the atmosphere. Thus 300 m-atm-cm of ozone is equivalent to 300 DU. A single DU corresponds to approximately 1 part per billion of ozone.

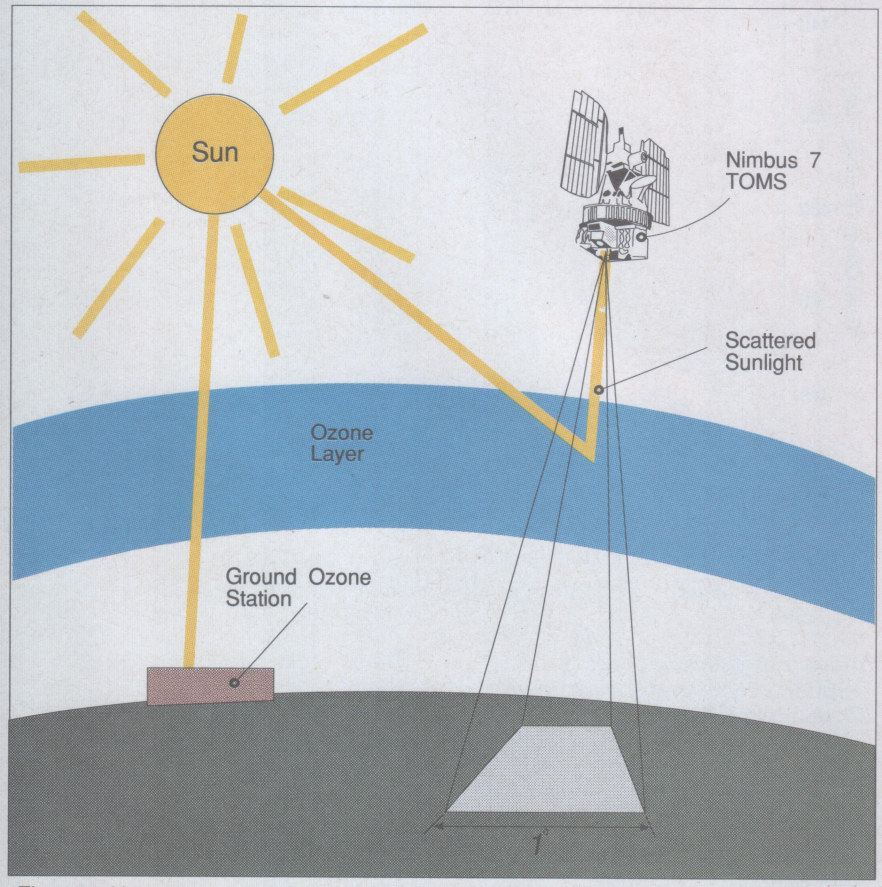


Figure 4. How ozone is measured from space and the ground.

Instruments that use optical filters to measure two or more UV wavelengths are more economical, smaller, and easier to use than the Dobson and the Brewer. They also provide information about the Sun's direct UV. For these reasons, I selected the filter approach several years ago when designing an instrument to measure total ozone.

Sensors on satellites can measure the amount of ozone at various altitudes by observing the Sun as it rises and sets through the atmosphere above the Earth's limb (an astronomical term referring to the edge of the disk of a planetary body). Other satellite sensors measure the amount of the Sun's UV that is scattered back into space from the atmosphere below. Because these wavelengths are absorbed by ozone, processing the backscatter from one or more pairs of wavelengths permits most of the amount of ozone between the satellite and the ground to be computed.

It's important to note that a satellite ozone instrument cannot measure all the ozone between the top of the atmosphere and the Earth's surface. Clouds can get in the way, and little or none of the UV backscattered from the lowest few kilometers above the surface can penetrate the ozone layer above.

Therefore a correction factor for the lower tropospheric ozone is inserted into the mathematical equation that transforms the signals from the satellite into the amount of ozone. The correction factor is based on measurements made from the ground during annual calibration checks, and measurements made by balloon-borne instruments.

Stratospheric Ozone Cycles

Superimposed on the daily ozone cycle near the ground are seasonal changes in the amount of stratospheric ozone. In the Northern Hemisphere, the total amount of ozone is lowest during winter. The amount of ozone peaks in the spring and gradually diminishes in the summer and fall.

This gradual seasonal variation in ozone is marked by sharp spikes and dips associated with weather systems. Passage of a cold front, for example, may cause the amount of ozone to increase by 20% or more for a day or two. A warm front may cause an equivalent but temporary decrease.

Meteorologists refer to regions of diminished ozone as ozone minimums, and regions of high ozone as



ozone maximums. I'll never forget the giant ozone maximum that passed over South Texas on March 16, 1990.

That morning I made a few ozone observations around 11 a.m. and was surprised to find the highest amount of ozone I had ever measured, around 360 DU. Because the ozone amount kept climbing as noon approached, I assumed something was wrong with my instrument. But both filters were clean, no wires were dangling in front of them, and the battery was fresh.

After 1 p.m. the ozone amount suddenly climbed much faster than it had before noon. By 1:30 p.m. it was more than 440 DU, and shortly before 2 it reached 460 DU. The ozone amount then began a sharp slide to the pre-noon amount.

Several months later, data from the TOMS (Total Ozone Mapping Spectrometer) instrument aboard the Nimbus-7 satellite confirmed the extraordinarily high ozone levels of March 16. My son, Eric, wrote a Pascal program that transformed the TOMS data into a color-coded ozone map of the United States.

The map disclosed an enormous tongue of high ozone reaching down from Canada and ending in South Texas. A check of weather records revealed that this ozone maximum was associated with a giant weather system that moved in from the Pacific and crossed the United States over a 3-day period.

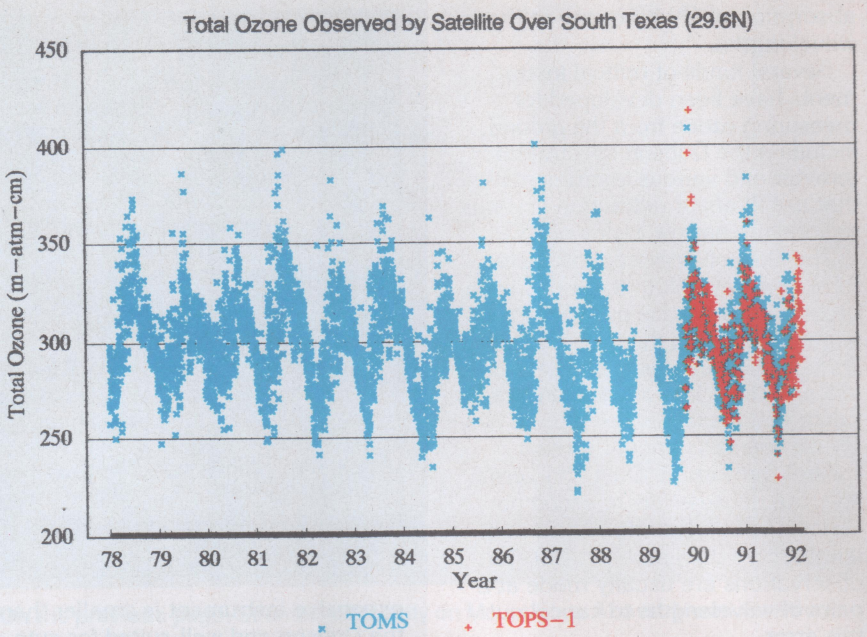
Stratospheric Ozone Trends and Effects

Recall that most ground observations of the ozone layer measure the total amount of ozone in a column between the instrument and the top of the atmosphere. Therefore, these measurements include the total amount of both tropospheric and stratospheric ozone.

Daily measurements of the amount of total column ozone have been made at Arosa, Switzerland, since 1926. The total amount of ozone back to 1912 has been determined by a careful analysis of solar measurements made by the Smithsonian Institution. Since 1957, more than 70 Dobson spectrophotometers have made regular measurements of ozone.

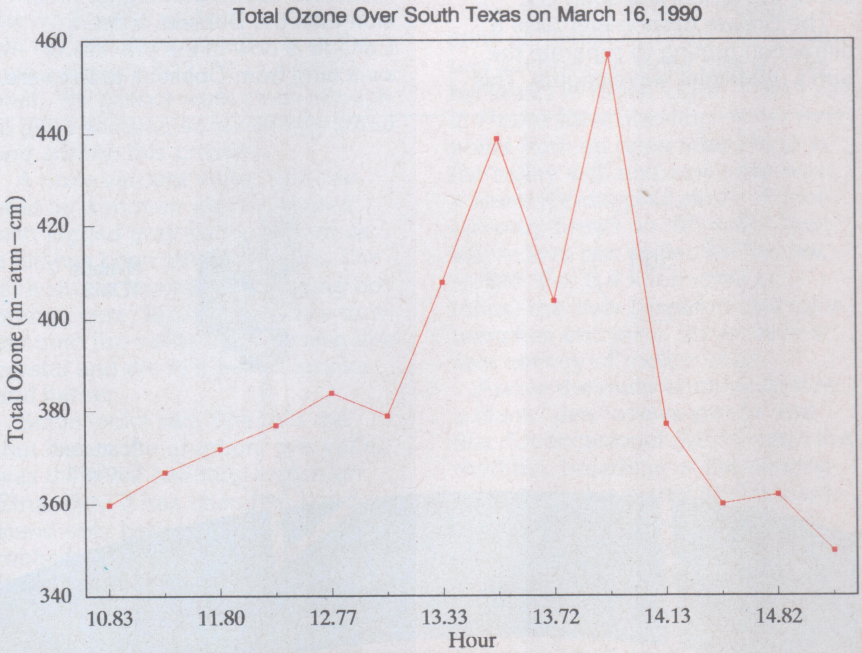
These measurements show that the total amount of ozone varies in cycles that may last a decade or more. For example, during the 1960s, scientists at the National Oceanic and Atmospheric Administration (NOAA) found that ozone over North America increased by about 5%. Since 1970, however, ozone over the Northern Hemisphere has declined about 5%. Because this decline is seen in measurements both from the ground and from satellites, there is little disagreement that it is real. But there is considerable disagreement concerning the **reason** for the decline, and its significance.

Some scientists believe the decline is primarily a by-product of natural meteorological cycles, a changing climate and possibly the solar cycle. They support their case



TOMS Satellite Date: NASA GSFC (A. Krueger et al)
TOPS-1: Forrest M. Mims, III

Figure 5. Annual cycles are obvious in this graph of the total ozone over the *Science PROBE!* field office in South-Central Texas from November 1, 1978 to May 25, 1992. Blue represents Nimbus-7 satellite observations. Red represents observations using TOPS-1. (Satellite observations shown here for 1989 are incomplete and may be 8% too low.)



TOPS-1 Ozone Measurements: Forrest M. Mims, III

Figure 6. Unusually high ozone measured at the *Science PROBE!* field office on March 16, 1990.

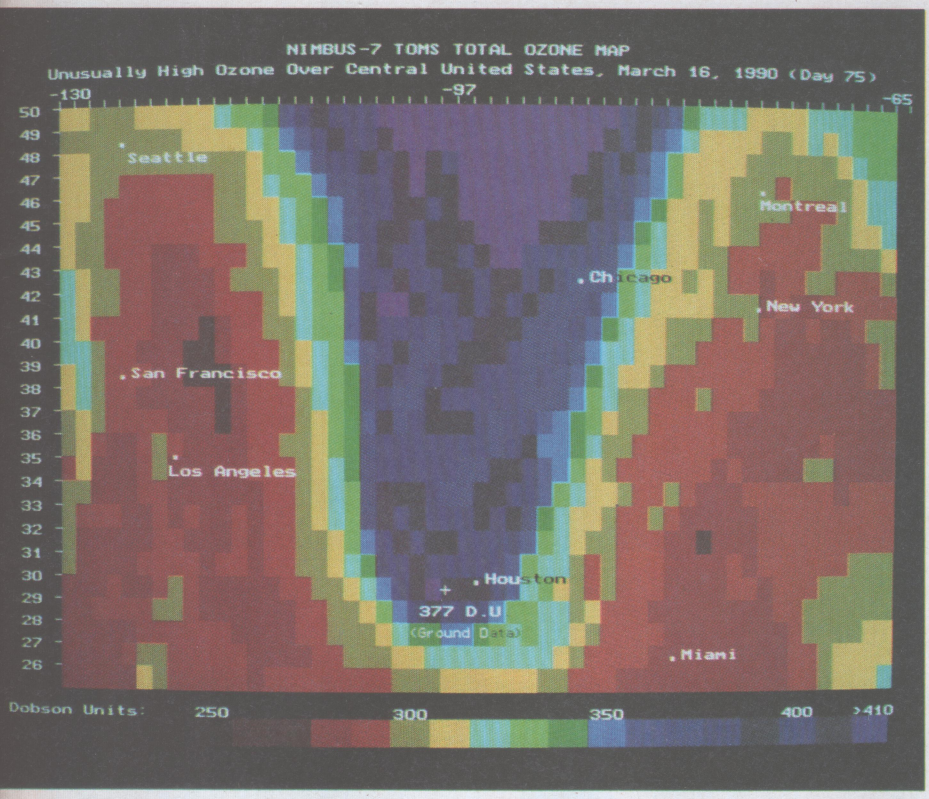


Figure 7. Color-coded ozone map of the United States for March 16, 1990. Note the tip of the tongue of high ozone levels that extends into South Texas. (Computer-generated ozone map by Eric R. Mims using ozone data supplied by NASA.)

by pointing to ozone cycles over the past 50 or more years. Others believe the decline is in large part because of contamination of the atmosphere by pollutants that contribute to the destruction of ozone, particularly CFCs. Some scientists believe the eruption of major volcanoes such as El Chichon in 1982 and Pinatubo in 1991 exacerbated the problem. Still other scientists believe ozone is affected both by natural meteorological trends and ozone-destroying chemicals.

These issues are being studied and debated by the scientists who study ozone. Meanwhile, as has been widely reported in the press, there has been considerable political fallout over the issue of declining ozone.

That's one reason why more than 70 nations have signed the Montreal Protocol, an agreement to eventually ban production of most CFCs. Because it is believed that CFCs can remain in the atmosphere for decades, even a total ban will not restore the ozone to its pre-1970 condition — if indeed CFCs are the principal culprit. Instead, ozone will likely continue to decline at, perhaps, a few percent or so per decade until CFCs are no longer present.

Ultraviolet Radiation

If the spectral sensitivity of a honey bee's eyes could somehow be added to yours, rainbows would have an additional streak of color adjacent to the violet band. This invisible band of "black light" is known as UV radiation.

UV radiation is divided into three sections. The wavelengths below 290 nm are referred to as UV-C. The wavelengths between 290 and 320 nm are referred to as UV-B. And the wavelengths between 320 and 340 nm are known as UV-A. The ozone layer blocks all UV-A. The UV-B that leaks through is what causes sunburn.

The Ultraviolet Sky

The daytime sky is blue because most of the molecules in the atmosphere are just the right size to scatter the blue wavelengths of sunlight. These molecules also scatter UV wavelengths. Ozone absorbs all the UV-C. This means that the entire daytime sky is a gigantic source of UV-A and UV-B.

The UV radiation from the sky can be described as direct, diffuse or global. Direct radiation is that received directly from the Sun. Diffuse radiation is that scattered from clouds and molecules of air. Global is the sum of direct and diffuse UV radiation. (See Figure 8 on the next page.)

Most natural materials reflect UV rather poorly. But snow is an excellent UV reflector; so is water. Therefore, exposed parts of your body can receive a significant dose of UV even when shaded from the direct Sun. Many people have experienced this phenomena very painfully — snow blindness or sunburn because of reflection from snow or water.

Ultraviolet Hazards

The energy of electromagnetic radiation is inversely related to its wavelength. In other words, radiation with short wavelengths, like X-rays, has much higher energy than radiation with longer wavelengths, such as visible light. For this reason, a photon of UV radiation is more energetic than a photon of visible light.

That's why the Sun's UV-B radiation causes erythema, a medical term for the reddening of the skin or sunburn, while UV-A and visible sunlight do not, even though there is much more of it. (Of course even visible sunlight will cause sunburn if it is concentrated with a lens or reflector.) The Sun's UV-B can also cause damage to the chromosomes of cells in human skin. This damage can eventually lead to skin cancer. Excessive UV-B can also alter the immune system and damage vision by causing cataracts.

Plants can be damaged by excessive UV-B. So can organisms that live for at least part of their life cycle near the surface of lakes, rivers and oceans. More research is needed to better understand the nature of such damage and the amount and wavelengths of UV that are responsible.

Ultraviolet Benefits

Because of concern about the possibility of thinning ozone, the public has been frequently reminded about the dangerous side of exposure to excessive solar UV. However, it's important to realize that UV from the Sun also plays an essential role in human health.

Perhaps the most important contribution of solar UV is its ability to stimulate the production of vitamin D in the outer layers of the skin. This gives UV the ability to prevent and to cure rickets and to maintain a healthy skeleton. Both natural and artificial UV radiation are used to treat psoriasis.



Measuring Ultraviolet Radiation

If you've ever retrieved a rolled up newspaper that has lain under the summer Sun for a few hours, you know that the newsprint paper darkens when exposed to solar UV. So does freshly cut or sanded pine and other woods. Colored construction paper and fabrics are bleached by solar UV.

Some chemicals will change color when exposed to solar UV. But an electronic instrument is necessary for a quantitative measurement of the intensity of UV. The two principal kinds of UV sensors used with such instruments are phototubes and solid-state detectors. Specialized phototubes known as photomultipliers can be made exceptionally sensitive to UV. But they are expensive, fragile and require a high operating voltage. Solid-state detectors are not as sensitive, but they are cheaper, sturdier and much easier to use.

An optical filter can be placed between a UV detector and the Sun to enable the detector to respond only to specific regions of the UV spectrum. Alternatively, a prism or grating can be used to select specific wavelengths.

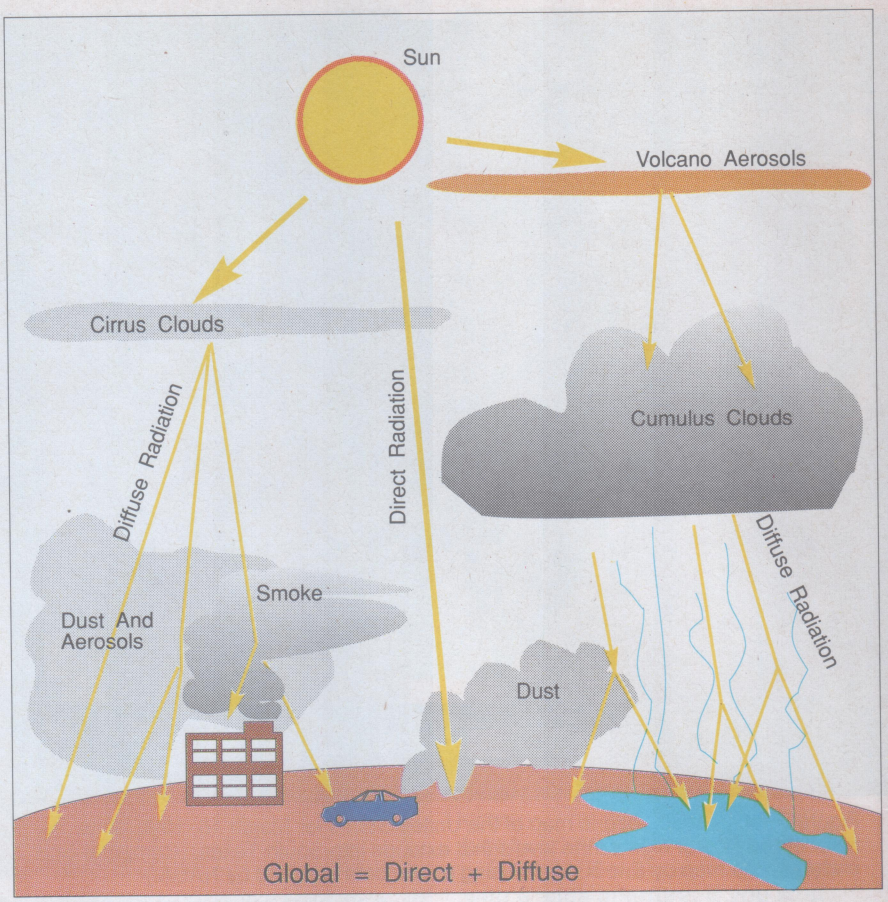
Various methods are used to measure direct, diffuse and global UV. Direct UV is easily measured by placing the detector inside a collimator tube that limits its field of view. Ideally, the field of view of the collimator should not exceed a few degrees. (The Sun subtends an angle of about 0.5°.)

Global UV is measured by placing a diffuser plate (such as ground silica or diffuse UV-transmitting plastic) over the detector and its filter.

Diffuse UV can be measured with a global detector by placing a small disk so that its shadow completely covers the detector. This blocks direct sunlight so that the detector signal is entirely from the diffuse sky. Subtracting the diffuse value from the global value gives the direct UV value.

Ozone vs. Sunlight

Ozone absorbs some of the Sun's infrared radiation. It even weakly absorbs the wavelengths around 600 nm, which appear orange to the human eye. Its most important absorp-



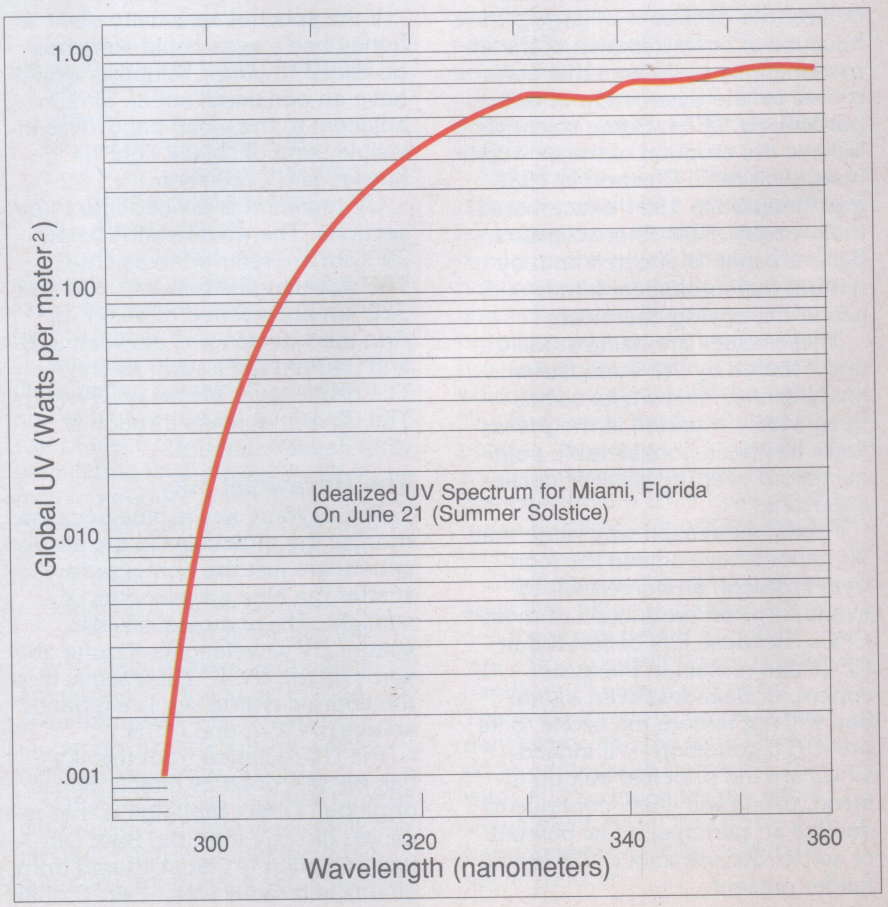


Figure 8. (Above right) Direct, diffuse and global solar ultraviolet radiation.

Figure 9. The sharp cutoff of solar UV is primarily because of absorption by ozone.

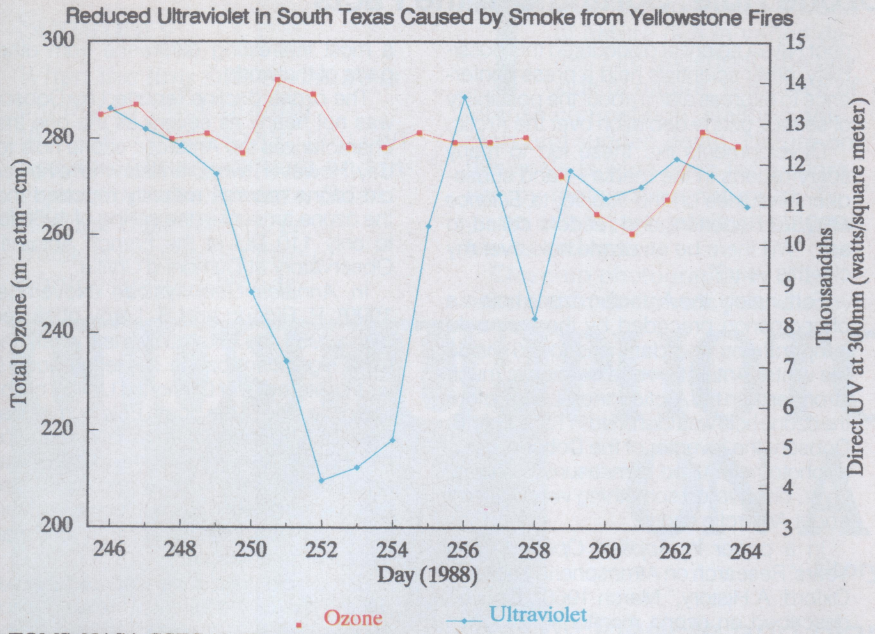


Figure 10. Smoke from the Yellowstone fires during the fall of 1988 drifted over the *Science PROBE!* field office in South Texas, where it caused a reduction of solar UV at 300 nanometers.

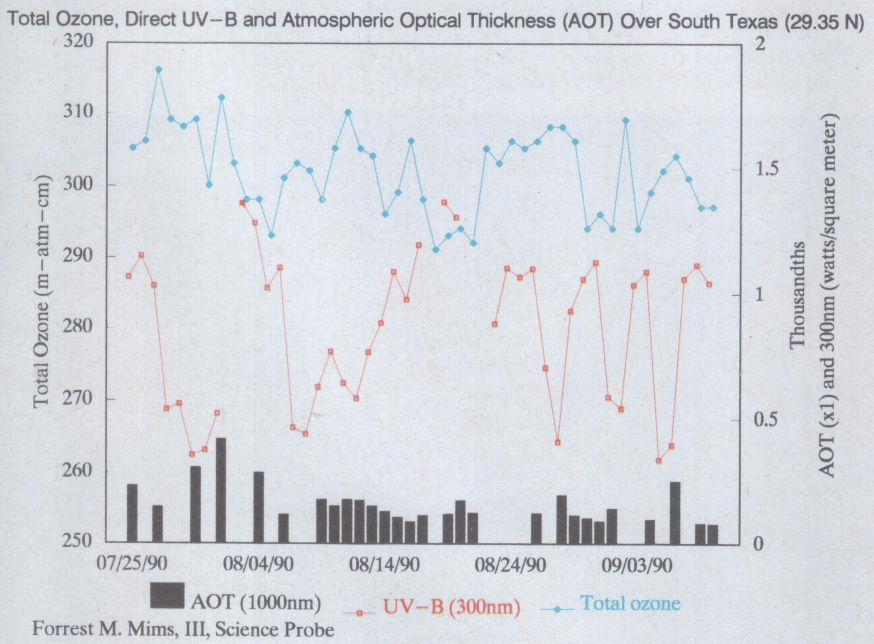


Figure 11. Higher ozone reduces UV-B — but so does increased optical depth of the atmosphere caused by dust, smoke and aerosols. This graph shows both effects.

A Low-Tech UV-B Detector

A few years ago during a *Science PROBE!* field trip to New Mexico, Eric and I tacked a strip of freshly sanded pine atop the crate bolted in the back of our pickup, which carried our instruments and supplies. We covered the wood with a strip of tape, several centimeters of which we removed each day.

After 10 days on the UV-drenched highways of Texas and New Mexico, the strip of wood was divided into 10 segments, each slightly darker than the next.

tion, of course, occurs at UV wavelengths below around 340 nm. The absorption increases so rapidly below 320 nm that little or no measurable radiation below 295 nm reaches the Earth's surface at sea level.

As noted, it's important to understand that scattering caused by dust and aerosols can cause ozone near the ground to absorb more UV than an equal amount of ozone in the stratosphere. This helps explain why some scientific studies have found a slight decrease in UV-B over the past decade, a time during which the amount of stratospheric ozone has decreased and the amount of tropospheric ozone has increased. ✳

FURTHER READING

Over the past half century, hundreds of scientific papers, articles and books have been published about ozone and solar UV.

If you want to study the history of the subject, the best paper by far is one by G.M.B. Dobson himself, "Forty Years' Research on Atmospheric Ozone at Oxford: A History" (*Applied Optics*, vol. 7, no. 3, March 1968, pp. 387-405).

Another outstanding paper, by one of Dobson's contemporaries, F.W. Paul Gotz, is "Ozone in the Atmosphere" (*Compendium of Meteorology*, American Meteorological Society, 1951, pp. 275-291).

The most recent comprehensive scientific paper on ozone trends is "Measured Trends in Stratospheric Ozone" by Richard Stolarski, Rumen Bojkov and several others (*Science*, vol. 256, April 17, 1992, pp. 342-349). This paper presents a detailed comparison of satellite and ground-based measurements and concludes that there is "an apparent downward trend in the total column amount of ozone over mid-latitude areas of the Northern Hemisphere in all seasons."

You can find many other articles about ozone at any library. University libraries are best, because they have many of the scientific journals that publish papers about ozone. Several books about ozone have also been published.

Keep in mind that some books and articles about ozone are not as objective as most scientific papers on the subject. The clash over ozone is especially well demonstrated by the cover story in the February 17, 1992, issue of *Time* and a response in the form of a cover story in the April 6, 1992, issue of *Insight*. If you read the first ("Vanishing Ozone"), be sure to read the second ("Vanishing Facts").

The Ozone Hole: Sorting Out the Facts

This sequence of color-coded images shows the amount of ozone above the Southern Hemisphere from 1979 to 1990. The images were made by the TOMS (Total Ozone Mapping Spectrometer) instrument aboard the Nimbus-7 satellite.

Most notable is the emergence of the significant reduction in ozone over Antarctica known as the "ozone hole." This widely publicized phenomenon is observed each year in October during the Antarctic spring. After several weeks, the Antarctic vortex, a whirling weather system that encircles and isolates the South Pole during winter, breaks up, and ozone levels rapidly rise.

In meteorological terms, the Antarctic ozone hole is a significant ozone minimum and not a literal "hole" through the entire ozone layer. Nevertheless, for a brief time ozone levels within the hole can plummet to 150 DU or even lower. At the same time, the ozone levels in a broad belt encircling the hole are the highest on Earth.

Because various scientific studies have concluded that the ozone hole is caused in part by chlorine believed to come from manufactured chemicals, especially CFCs, some scientists, politicians and government agencies have sounded an alarm about the prospect of severe ozone depletion leading to ozone holes elsewhere. In a widely publicized statement earlier this year, Sen. Albert Gore raised the possibility that an ozone hole might appear over Kennebunkport, Maine. Although a prominent NASA scientist discounted this possibility, other scientists held a press conference to express alarm about the possibility of serious ozone depletion over the Arctic.

Developments like these led to many scary reports in the media — and subsequent inquiries on the subject to *Science PROBE!* Reporters and readers called to ask, "Will there be an ozone hole over my city this year?"

Fortunately, the Antarctic ozone hole is a phenomenon preceded by the very cold temperatures and darkness found inside the winter Antarctic vortex, which is much stronger than the Arctic vortex. Long before the ozone hole was identified in 1985, G.M.B. Dobson, the inventor of the Dobson spectrophotometer used to measure the ozone layer, discovered something very different about Antarctic ozone.

In a paper in *Applied Optics* ("Forty Years' Research on Atmospheric Ozone at Oxford: A History," March 1968), Dobson described an ozone monitoring program that began at Halley Bay, Antarctica, in 1956.

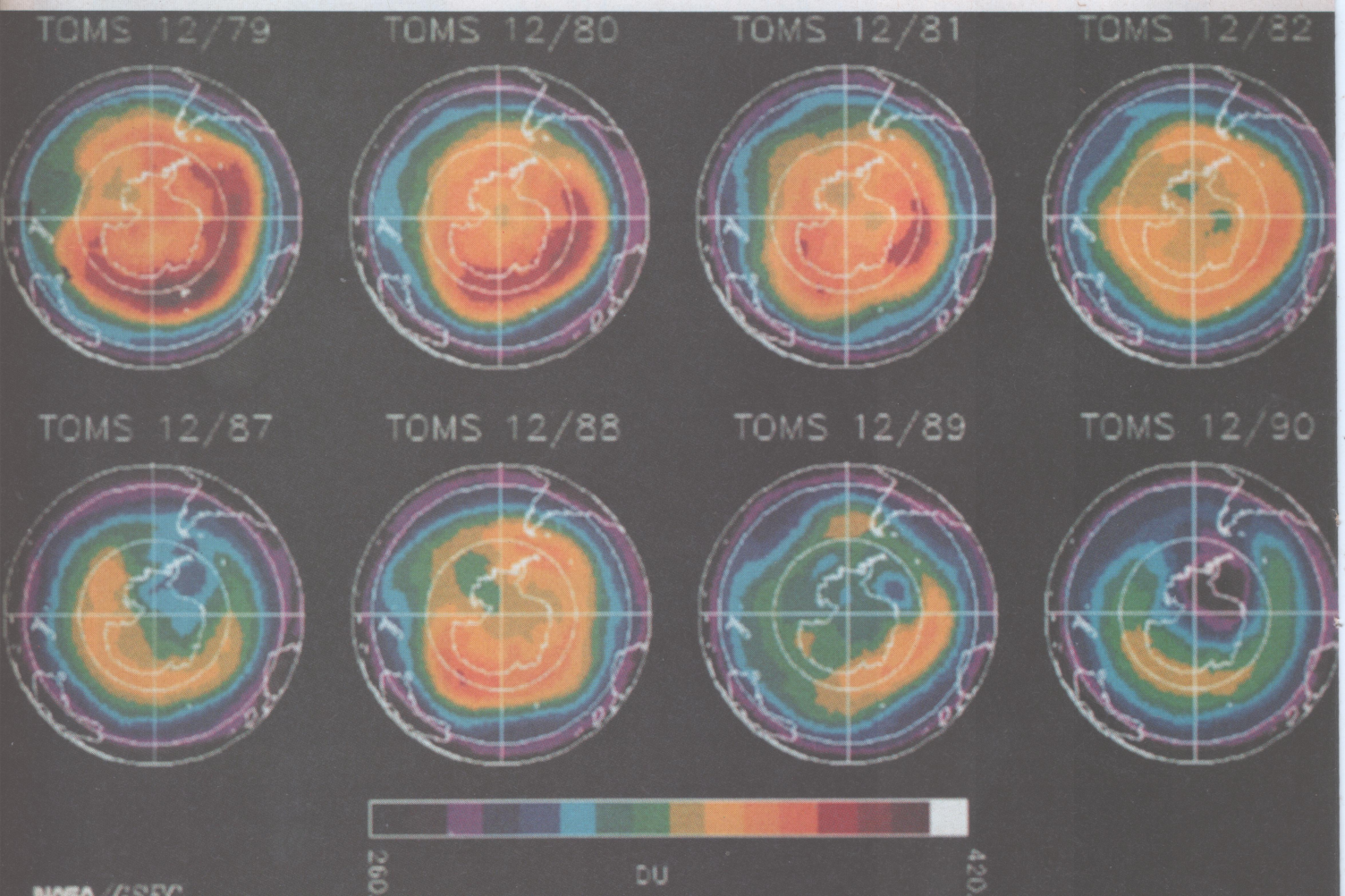
When the data began to arrive, ". . . the values in September and October 1956 were about 150 [Dobson] units lower than expected. . . . In November the ozone values suddenly jumped up to those expected. . . . It was not until a year later, when the same type of annual variation was repeated, that we realized that the early results were indeed correct and that Halley Bay showed a most interesting difference from other parts of the world."

The ozone decline reported by Dobson was not nearly as severe as the one that characterizes the Antarctic ozone hole today. However, two scientists who reviewed old ozone records recently reported that the ozone amount in the spring of 1958 fell to only 110 DU at the French Antarctic Observatory at Dumont d'Urville.

In *Annales Geophysicae* (November 1990), P. Rigaud and B. Leroy observed that in 1958, the Antarctic vortex, where the most significant ozone depletion occurs, was centered over Dumont d'Urville, on the opposite side of the South Pole from Halley Bay. They reported that the concentration of CFCs in the atmosphere in 1958 was much lower than it is today and concluded that natural phenomenon such as volcanic aerosols in the stratosphere may also lead to ozone destruction.

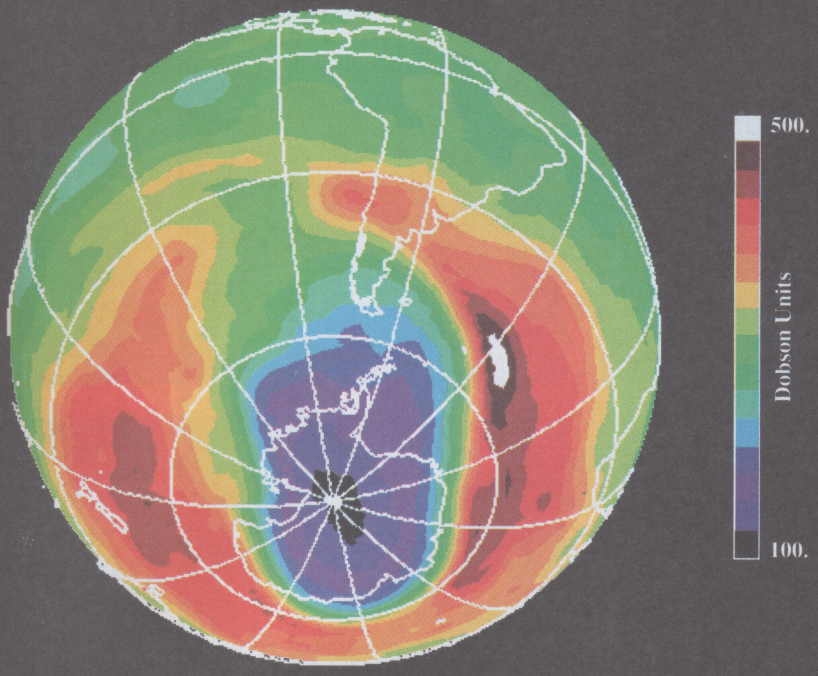
Some scientists have disputed the paper by Rigaud and Leroy. Their suggestion about possible volcanic effects on ozone will soon be tested if aerosols from last year's eruption of Mt. Pinatubo, one of the biggest of the century, reach Antarctica before the winter vortex forms.

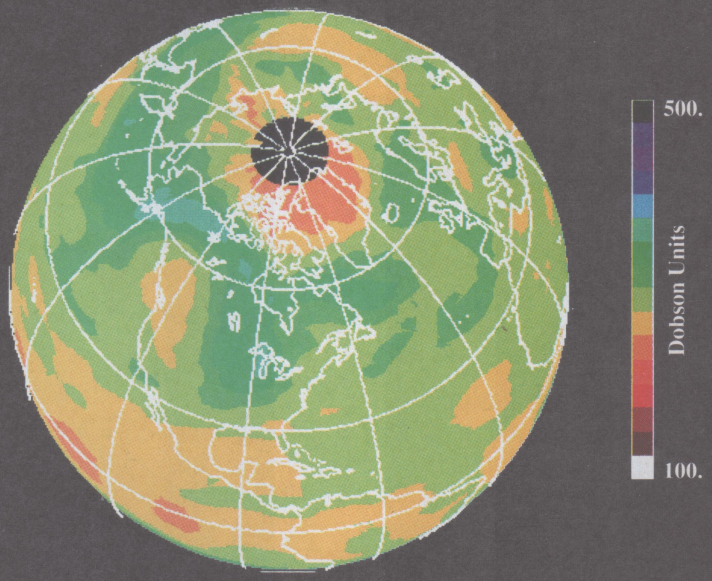
Meanwhile, the chemistry and dynamics of the atmosphere inside the Antarctic and Arctic vortexes remain the subject of extensive and expensive research using various kinds of ground-based instruments, instrumented balloons, high-flying aircraft and several different satellites.

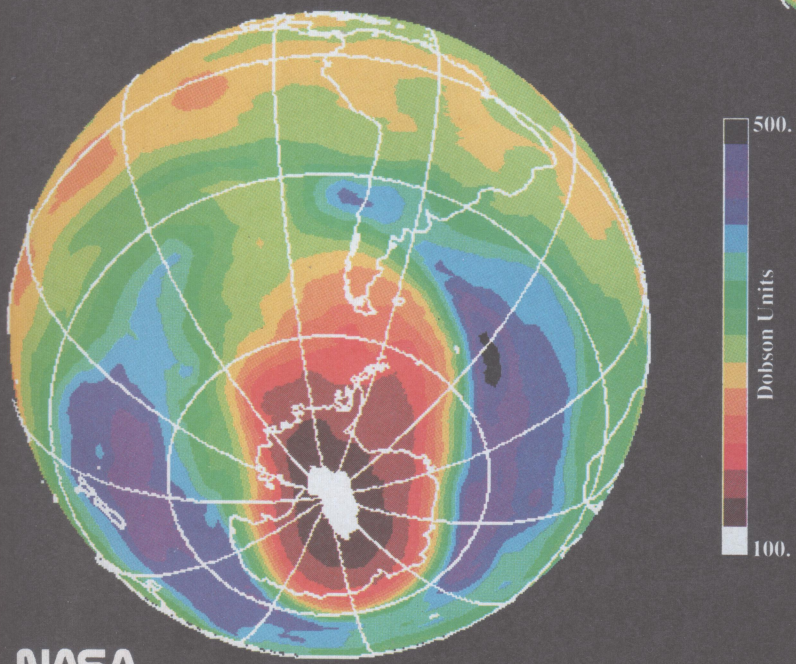


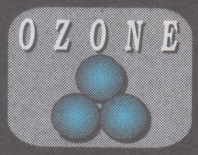
Coloring the Ozone

October 5, 1991 TOMS total ozone









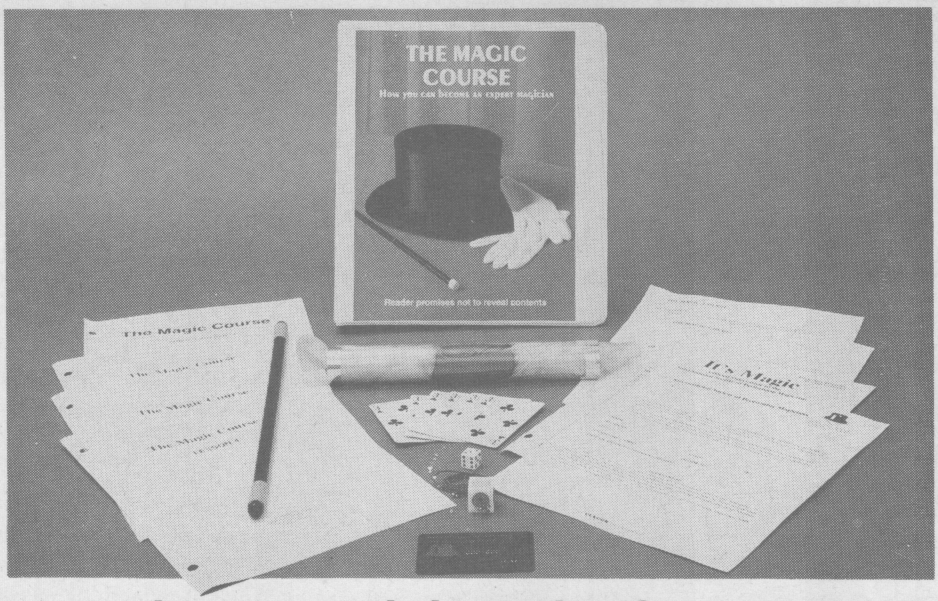
The image on the cover and the images on this page display the amount of ozone in the Earth's atmosphere on October 5, 1991. The data for all the images was collected by the Total Ozone Mapping Spectrometer (TOMS) aboard Nimbus-7, a satellite launched by NASA in 1978.

The ozone amount in each image is indicated by the adjacent color code bar. Most previously published ozone images use a rainbow color code similar to the image at left, in which low ozone is denoted by black and high ozone by white. However, because ozone is a blue gas and because red signifies danger, Eric and I use a rainbow color code in which low ozone is denoted by red and high ozone by blue as in the images below. The TOMS image on the cover and the images on the lower part of this page use this color code.

The most dramatic feature of the images of the Southern Hemisphere is the large area of significantly depleted ozone over Antarctica known as the "ozone hole." Notice the very high level of ozone on opposite sides of Antarctica. After the winter vortex breaks up, this ozone moves south and helps restore the ozone over Antarctica. The black disk over the North Pole in the image of the Northern Hemisphere is caused by the absence of sunlight.

These ozone images were made possible by the TOMS Ozone Processing Team. We are especially grateful to Paul Newman of NASA's Goddard Space Flight Center for providing images with examples of both color codes.

NASA



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How to Measure the Ozone Layer

By Forrest M. Mims, III, Editor

A Special Installment of "Science Experimenter"

Summary

The total amount of ozone in a column through the atmosphere can be determined by measuring two wavelengths of the ultraviolet radiation emitted by the Sun. An instrument that performs such measurements is the subject of this special installment of "Science Experimenter." Sufficient details are included for advanced experimenters to design their own ozone-monitoring instruments.

The amount of ozone between the ground and the top of the atmosphere can be measured with an instrument that is pointed at the Sun. Since 1989, I have designed and built several instruments capable of making such measurements. These instruments also provide data about direct solar ultraviolet.

For test purposes, I have assembled two nearly identical instruments called TOPS-1 and TOPS-2. (TOPS stands for **T**otal **O**zone **P**ortable **S**pectroradiometer.) Sufficient information is given here to enable advanced experimenters to assemble a TOPS instrument. Even if you do not plan to build a TOPS instrument, this article should give you considerable insight into one way the ozone layer can be accurately measured from the ground. For, as Figure 1 confirms, the TOPS instruments do indeed provide accurate data about the ozone layer.

Measuring Ozone

Ozone strongly absorbs ultraviolet (UV) radiation from the Sun with a wavelength below about 330 nanometers (nm). This absorption is so efficient that under normal conditions practically no radiation with a wavelength below 295 nm reaches the ground.

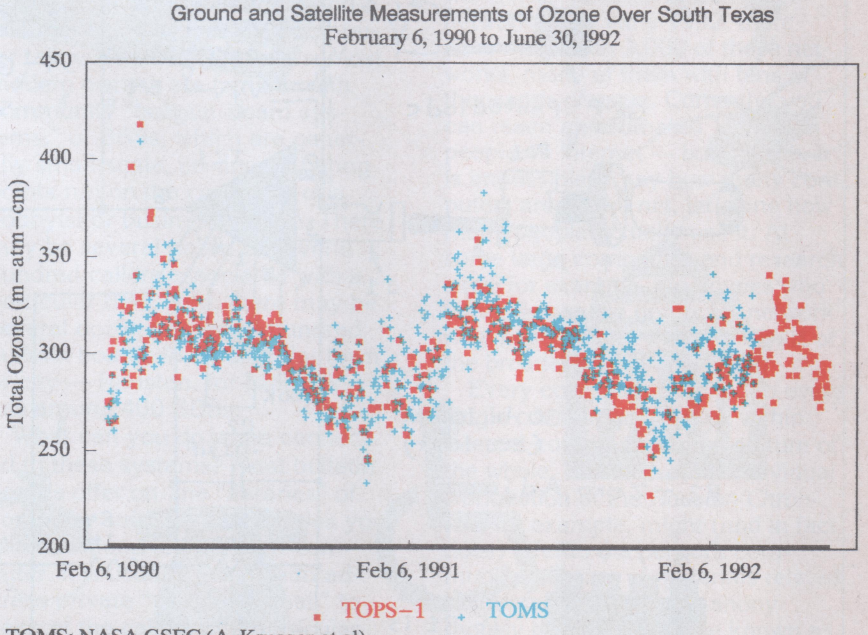
Ozone absorbs shorter wavelengths of UV much more efficiently than longer wavelengths. Therefore, the amount of ozone can be measured by a method known as *dual-*

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Photo by Eric R. Mims

The author measures ozone near a large thunderstorm in the New Mexico desert north of Carlsbad Caverns.



TOMS: NASA GSFC (A. Krueger et al)
TOPS-1: Forrest M. Mims, III

Figure 1. Comparison of ozone measurements made by the author using TOPS-1 in South Texas with nearly simultaneous observations by the TOMS instrument aboard the Nimbus-7 satellite.

wavelength absorption spectroscopy.

This method is, in principle, very simple. A TOPS instrument, for example, is simply a pair of UV radiometers installed in a single housing. The difficult part of measuring ozone is the various formulas that transform a pair of UV measurements into the amount of ozone. We shall discuss this topic later. First, let's examine the details of a working instrument.

The TOPS Ozonometer

In this and previous issues of *Science PROBE!*, I have referred to various measurements made with TOPS-1 and TOPS- 2. These filter ozonometers are similar in principle to the ozonometer first developed by A.L. Osherovich of the former Soviet Union and expanded on by W. Andrew Matthews and Reid E. Basher of New Zealand. The TOPS instruments are much smaller than these earlier instruments.

To make an ozone observation, a TOPS instrument is pointed directly at the Sun. UV radiation passing through the filters strikes the two detectors, which are 2-terminal photodiodes that convert light into an electrical current. The signal from each detector is amplified and sent to a miniature digital readout.

Although advanced experimenters should be able to assemble a TOPS instrument, it is important to understand that the necessary pairs of UV filters, photodiodes and high-resistance resistors are not readily available.

Selecting the Filters

The most important and expensive components of a TOPS instrument are the two UV filters. Most previous filter ozonometers respond to a pair of wavelengths separated by about 20 nm, but this means errors can be introduced by aerosols in the atmosphere. I minimize this problem by using wavelengths only 6 nm apart.

To make sure there is ample difference in the ozone absorption at two wavelengths this close together, it's necessary to use wavelengths close to the point at which all UV radiation is blocked by ozone because that's where the difference in absorption is most dramatic. I use wavelengths of 300 and 306 nm. These wavelengths work well at my latitude, 29° 35' north, but they will not work well at higher latitudes during winter and spring because of the lower Sun angle and the increased amount of ozone.

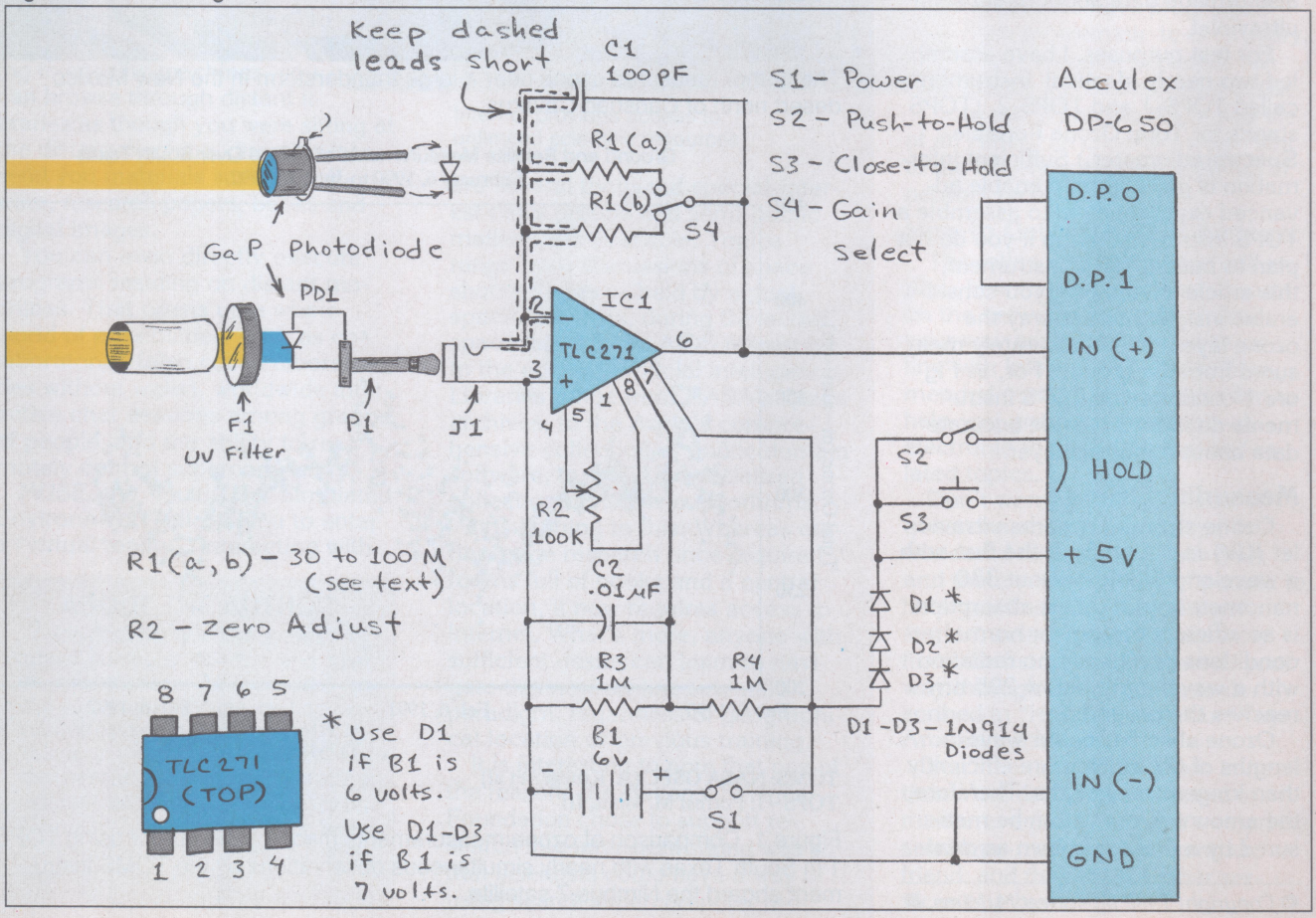
A better pair of wavelength ranges for locations above around 35° north would be 305 to 310 nm for the short wavelength and 325 to 330 nm for the long wavelength. The disadvantage of these wavelengths is that aerosols in the atmosphere may cause more error than with more closely spaced wavelengths.

For best results, the bandpass of filters used to detect ozone must be less than the 10 nm which is standard for most interference filters. The TOPS-1 and TOPS-2 filters each have a bandpass of 5 nm. If you cannot find filters with a 5 nm or less bandpass, you can reduce the bandpass of a 10 nm filter by stacking two of them.

Filters are commonly sold in diameters of 12.5 and 25 mm (0.5 and 1 in). Smaller filters are cheaper and easier to mount.

Stock UV interference filters cost $100 or more each, and custom filters are considerably more expensive. Manufacturers of stock filters include Twardy Technology, Inc.

Figure 2. Circuit diagram for one of the two channels in a TOPS ozonometer.



(P.O. Box 2221, Darien, Connecticut 06820), MicroCoatings (One Lyberty Way, Westford, Massachusetts 01886), and Andover Corporation (4 Commercial Drive, Salem, New Hampshire 03079). Additional manufacturers advertise in trade magazines for the optics and laser industries.

Building TOPS

Figure 2 is the circuit for one of the two identical UV radiometers in a complete TOPS instrument. Figure 3 shows how the various components are installed in an aluminum enclosure. If you have previous experience building miniature electronic circuits, you should be able to assemble your own instrument with these figures as a guide.

The prototype TOPS are installed in LMB CR-531 Crown Royal aluminum cases available from electronics distributors and Mouser Electronics (P.O. Box 699, Mansfield, Texas 76063; phone [800] 346-6873). Squeezing all the components into a CR-531 case requires careful planning; you can simplify assembly by using a larger cabinet. You must, however, make sure no light can leak between the filter and detector, and that the detector views a narrow cone with an angle of less than 2 degrees.

Because the signal from the photodiodes is very small, you must use a Texas Instruments TLC271CP or similar-quality operational amplifier; do not substitute a more common 741. If you substitute an even better quality amplifier, one or more of the pin connections may be different. The TLC271CP and R2 are available from various electronics distributors, including Newark Electronics. For a catalog, write Newark Electronics, 4801 North Ravenswood Avenue, Chicago, Illinois 60640-4496.

R1 is one or two very high resistance feedback resistors that are not widely available and whose values can be specified only approximately because of variations in signal transmitted by different filters at various wavelengths. I use two resistors to give two gain levels. Only one is needed if you plan to make measurements near noon throughout the year.

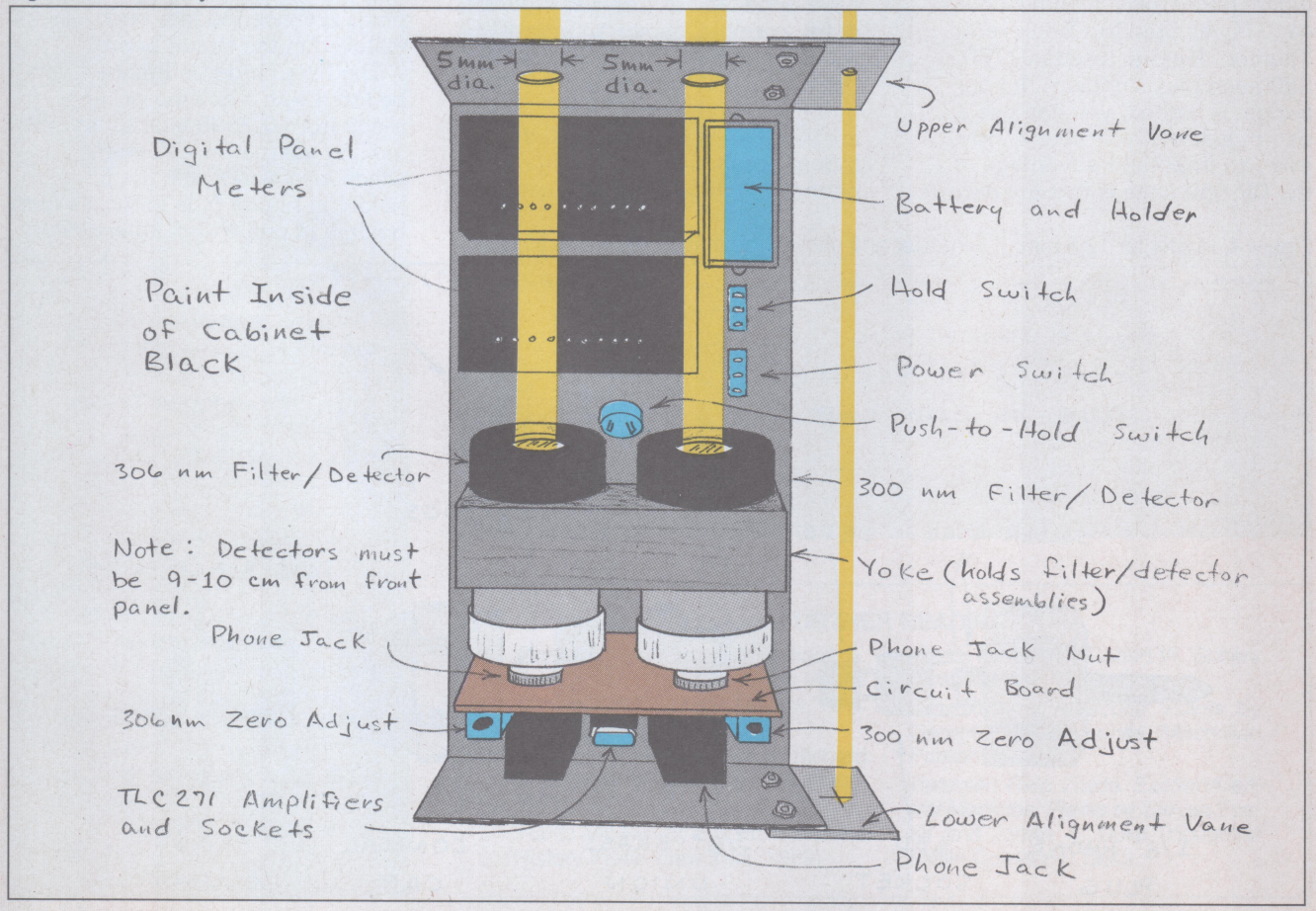
The optimum resistance will probably be between 30 and 100 megohms. The exact value is not critical; if 44 megohms works, then 32 megohms will work but with reduced gain.

I select the best value by inserting each of several resistors into the circuit temporarily while monitoring the readout, with the filtered detector pointed at the Sun. The selected resistance should cause the readout to display perhaps 80% or so of its full range for bright, noon Sun with low ozone conditions.

Resistors of more than 22 megohms are hard to find and expensive. You can make your own by soldering together a string of several 10 and 22 megohm resistors available from electronics parts stores. Use the smallest possible resistors (e.g. 0.1 watt), place them

Special Construction Note: The construction portion of this article requires intricate assembly procedures (including careful component positioning and soldering). It should be attempted only by readers with considerable electronics construction expertise. If you are seriously interested in measuring ozone and are unable to assemble your own instrument, see "SPAN Ultraviolet Filters" at the end of this article.

Figure 3. Assembly details for a TOPS ozonometer.



side by side, and keep the soldered leads as short as possible.

It's important to use gallium phosphide (GaP) photodiodes because they do not respond to the near-infrared radiation that leaks through most UV filters. UV-sensitive silicon photodiodes are cheaper, but they are very sensitive to near-infrared. Special blocking filters can solve this problem, but they are expensive.

Gallium phosphide photodiodes are made by Hamamatsu Corporation (P.O. Box 6910, Bridgewater, New Jersey 08807). The G1961 ($34.23 plus shipping) is housed in a TO-18 package and has an effective surface area of 1.0 square mm. The G1962 ($43.98) is housed in a TO-5 package and has a surface area of 5.2 square mm. The G1962 is a better choice for low signal levels at northerly latitudes and for wavelengths near 300 nm. (The G1962 will not fit the filter holder shown in Figure 4.)

The size of the UV filters and the digital readouts determines the size of the instrument. The prototype TOPS use large 25-mm filters and compact DP-650 ±200 millivolt digital panel meters from Acculex (440 Myles Standish Boulevard, Taunton, Massachusetts 02780; $60 each plus shipping). If your budget is limited, you can use a pair of external voltmeters. However, an important advantage of the DP-650 units is that the data in the display can be saved simply by pressing a push-button switch that connects Pin 11 to Pin 1 (+5 volts). A new reading can be made when the switch is opened.

The DP-650 readout must be powered by no more than 5.5 volts. Diodes D1-D3 in Figure 2 reduce the battery voltage to this level. If you use a 6-volt battery, only one diode is needed. Use all three diodes if you use a 7-volt battery.

You will need to make two light-tight mounts for the filters and detectors. Light can leak through the back of the detector, so it must be entirely installed inside the mount or its back must be coated with a non-conductive black paint.

If you have access to a machine shop, you can make filter holders from aluminum. Or you can do as I have done, and improvise. Figure 4, for example, shows an improvised mount for a G1961 photodiode and a 12.5 mm filter. The 25-mm filters in the prototype TOPS are installed in the improvised mount shown in Figure 5. The phone plug in both mounts provides a means for isolating the photodiode from external light. These plugs are inserted into phone jacks installed in the circuit board.

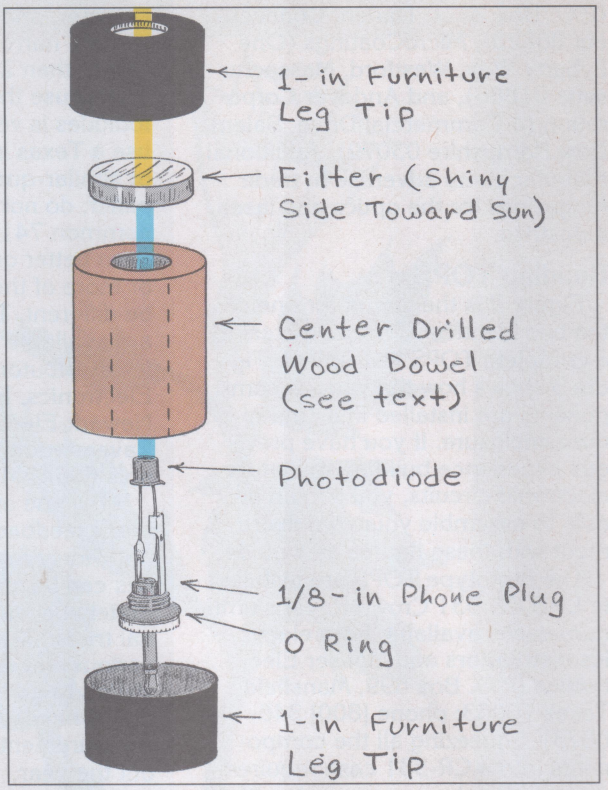
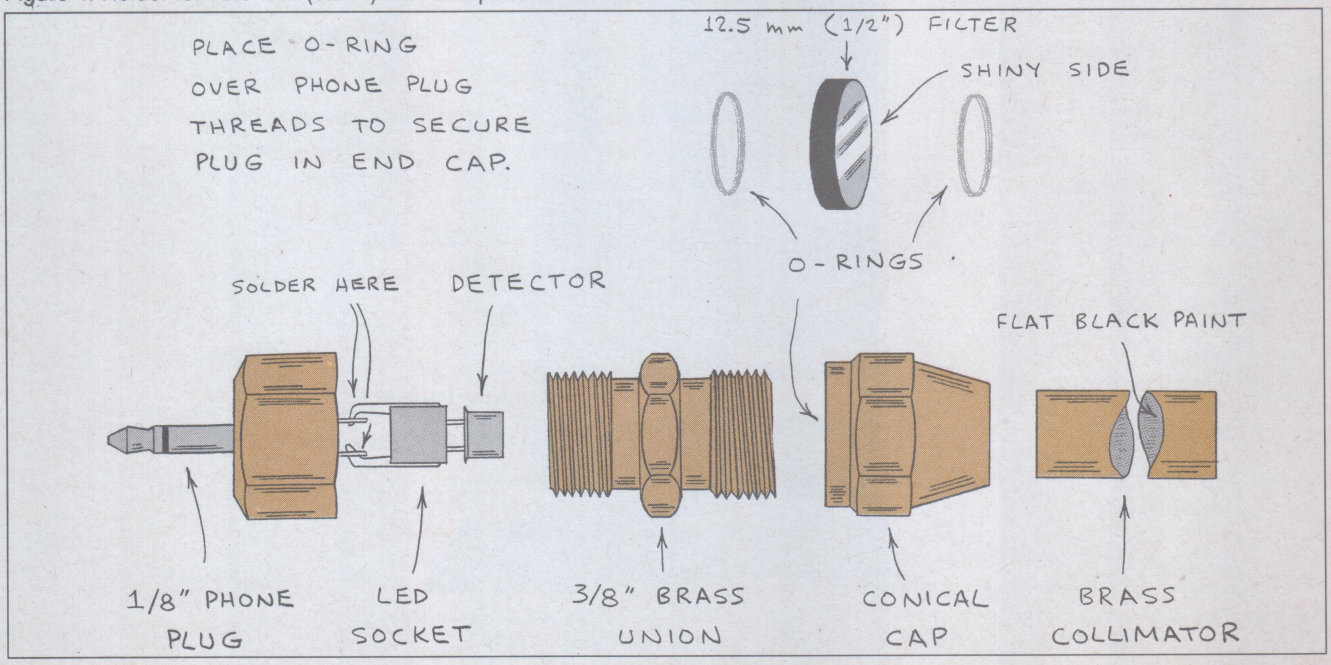


Figure 5. Holder for 25-mm (1.0-in) filter and photodiode made from two plastic furniture tips and a wood dowel.

The filter holder in Figure 4 can be fitted with a collimator tube made from 0.25-in aluminum tubing. An alternative collimator, which also works with the filter holder in Figure 5, is to mount both holders at one end of an enclosure

Figure 4. Holder for 12.5-mm (0.5-in) filter and photodiode made from a brass union.



and form a pair of matching apertures in the opposite end (see Figure 3). Carefully measure the distance between the two detectors before forming the holes, because both detectors must be perfectly centered in the circle of sunlight projected through the holes.

Testing and Aligning TOPS

After you assemble the instrument circuit, carefully check the wiring. It's especially important that the battery connections to the digital readouts and the amplifier be correct. If everything is in order, install a battery in the battery holder and switch on the instrument. Both readouts should display digits. Block both photodiodes and adjust the trimmer potentiometers (R2) until the two readouts read 0 volts.

A pair of aluminum vanes (see Figure 3) provides a means for optically aligning TOPS. Bore a small (1-2 mm) hole near the center of the upper vane. With the cabinet open, point the instrument at the Sun and align it until sunlight strikes both filters. Then place a small mark where sunlight from the upper vane strikes the lower vane.

If your filters are recessed, you can see when sunlight is striking them by placing a glass micro-

Computing the Ozone Amount

Determining the amount of ozone over your head requires several steps. Although complicated at first, they will become easy if you begin a regular measurements program.

Finding Local Mean Time

Solar noon for your location is not necessarily when your watch shows 12:00, especially if daylight-saving time is in effect. Complete details about how to determine the local time for your location are given in various books and magazines about astronomy and sundial making.

Briefly, the Earth rotates 360° in 24 hours. This is equivalent to 1° in 4 minutes, or 15° in 1 hour. The standard time longitudes or meridians range from 45° to 165° west in increments of 15°. Therefore, the time at each meridian is 1 hour earlier than the previous meridian.

To find your local time, first find the number of degrees between your longitude and your time meridian. Multiply the number of degrees by four to obtain the correction for your location. If you are east of the time meridian, add the correction to the standard time for your area; if you are west of the meridian, subtract the correction from the standard time. The result is known as your *local mean time*.

For example, the longitude for Omaha, Nebraska, is 96°, 6° west of the standard time meridian of 90°. This means the time correction is 6 x 4 or 24 minutes. Because Omaha is west of the meridian, 24 minutes must be subtracted from Central Standard Time to arrive at the local mean time for Omaha.

Over the course of a year, the Earth's orbit causes the Sun to run either ahead of or behind local mean time by as much as 16 minutes. The actual difference between local mean time and the actual or apparent time is called *the equation of time*. Computer programs that compute the Sun's angle (see next page) automatically determine the equation of time. For additional information, see "Further Reading."

Determining the Sun Angle

You will need to know the angle of the Sun above the horizon to compute the air mass and thus the ozone amount overhead. You can determine this angle manually or by formulas that require the date and the exact time.

If you measure the angle manually, be sure to do so immediately after making the observations. You can do as I have done and install a bubble level on your TOPS instrument to facilitate this measurement. Hold the unit on its side with the upper alignment vane pointed toward the Sun. When the bubble is centered, measure the length of the shadow cast by the upper vane.

The tangent of the Sun's angle above the horizon is the length of the upper vane divided by the length of the vane's shadow. If you are careful, you should be able to measure the Sun's angle to within a degree or so.

Whether or not you measure the Sun angle directly, it's very important to record the date and the exact time of your observations. The time information will permit you to calculate the Sun angle electronically at a later date should you elect to do so.

Various computer programs are available that give the angle of the Sun for any time on any day of the year for any location on Earth. Two such programs that I have often used are AstroCalc™ and AstroCalc Plus™ (Zephyr Services, 1900 Murray Avenue, Pittsburgh, Pennsylvania 15217).

My son, Eric, and I have devised a Lotus 1-2-3® (versions 2.1 or 3) spreadsheet program that permits a computer to calculate the angle of the Sun. This program is given in Table 1 on the next page. It should work with or be adaptable to other spreadsheet programs that include the necessary trigonometry functions.

The Total Ozone Equation

Various equations for computing the amount of ozone use Beer's law. A simplified version for two wavelengths, without taking aerosol scattering into effect, is

$$O_3 = \frac{\log (L_1^\wedge/L_2^\wedge) - \log (L_1/L_2) - (b_1 - b_2) \times (p \times m/1013)}{(a_1 - a_2) \times m}$$

where, $L_1^\wedge$ and $L_2^\wedge$ are the intensities of the two wavelengths outside the atmosphere;

L_1 and L_2 are the intensities of the two wavelengths during an observation;

a_1 and a_2 are the absorption coefficients for ozone at the two wavelengths;

b_1 and b_2 are the Rayleigh scattering coefficients for air at the two wavelengths;

m is the air mass (approximately 1/sin c where c is the angle of the Sun above the horizon); and

p is the mean barometric pressure of the observation site in millibars (inches of mercury times 33.864 gives pressure in millibars).

$L_1^\wedge/L_2^\wedge$, the ratio of the signal at the two wavelengths above the Earth's atmosphere, is known as the *extraterrestrial constant*. Unless you are a space shuttle astronaut, you'll need to measure this value from the ground by making a Langley graph on a very clear, dry day when the ozone amount remains fairly constant.

Record L1 and L2 (see below) and the time as often as possible for a few hours ending or beginning at solar noon. Plot the log of the ratio L1/L2 against air mass (m, the reciprocal of the sine of the Sun's angle above the horizon) on a graph. If you extend the plot to 0 air mass, as shown in Figure 6, you will find the approximate extraterrestrial constant.

The problem with the Langley graph method is that the effective center wavelength of a UV filter changes as the Sun's angle changes. Therefore, the line of points on the graph will begin to curve beyond some air mass. For very short wavelength filters, the line will begin to curve as early as m = 1.2 or so.

Since this problem is caused by the filter's bandwidth, narrow bandpass (< 3 nm) filters work much better than ordinary filters with a bandpass of 10 nm. In any event, when you extend the line formed by the dots to m = 0, ignore dots that curve.

An alternative way to find $L_1^\wedge/L_2^\wedge$ is to use satellite measurements of sunlight (see a recent edition of *Handbook of Chemistry and Physics*, CRC Press). Although I have had good results using this method, the bandpass of a UV filter limits its accuracy.

L_1/L_2 can be the ratio of the UV measurements in watts per square meter or simply the numbers read from the readouts. Because the ratio of the two signals is being measured, it's not necessary to know the calibration of the photodiodes.

The ozone absorption and Rayleigh scattering coefficients can be found in published tables. For ozone, see "Absolute Absorption Cross Sections of Ozone in the 185- to 350-nm Wavelength Range" by L.T. Molina and M.J. Molina in *Journal of Geophysical Research* (vol. 91, no. D13, Dec. 20, 1986, pp. 14,501-14,508). For Rayleigh scattering, see the second column of Table III in "Tables of the Refractive Index for Standard Air and the Rayleigh Scattering Coefficient" by Rudolf Penndorf in *Journal of the Optical Society of America* (vol. 47, no. 2, Feb. 1957, pp. 176-181).

Table 1. Lotus 1-2-3® Program for Computing Air Mass

```
A7: (D4) 33687 [DATE]
B7: (D8) (B:B7) [TIME]
C7: 84 [DAY NUMBER]
D7: [TOPS LOW WAVELENGTH]
E7: [TOPS HIGH WAVELENGTH]
F7: +D7/E7 [TOPS WAVELENGTH RATIO]
G7: [OZONE EQUATION]
H7: @HOUR(B7)+(@MINUTE(B7)/60)+(@SECOND(B7)/3600) [DECIMAL HOUR]
I7: (@PI/180)*(360*C7/365.25) [DAY ANGLE]
J7: @ASIN(0.3978*@SIN(I7-1.39975+0.03351*@SIN(I7-0.04887))) [SUN DECLINATION]
K7: (@PI/180)*15*(H7+((time meridian-site longitude)/15)+N7-12) [HOUR ANGLE]
L7: (@PI/180)*(latitude) [SITE LATITUDE IN RADIANS]
M7: @ASIN(@SIN(L7)*@SIN(J7)+@COS(K7)*@COS(L7)*@COS(J7)) [SUN ANGLE]
N7: -0.128*@SIN(I7-0.0489)-0.165*@SIN(2*I7+0.3438) [EQUATION OF TIME]
O7: (F4) 1/@SIN(M7) [AIR MASS]
```

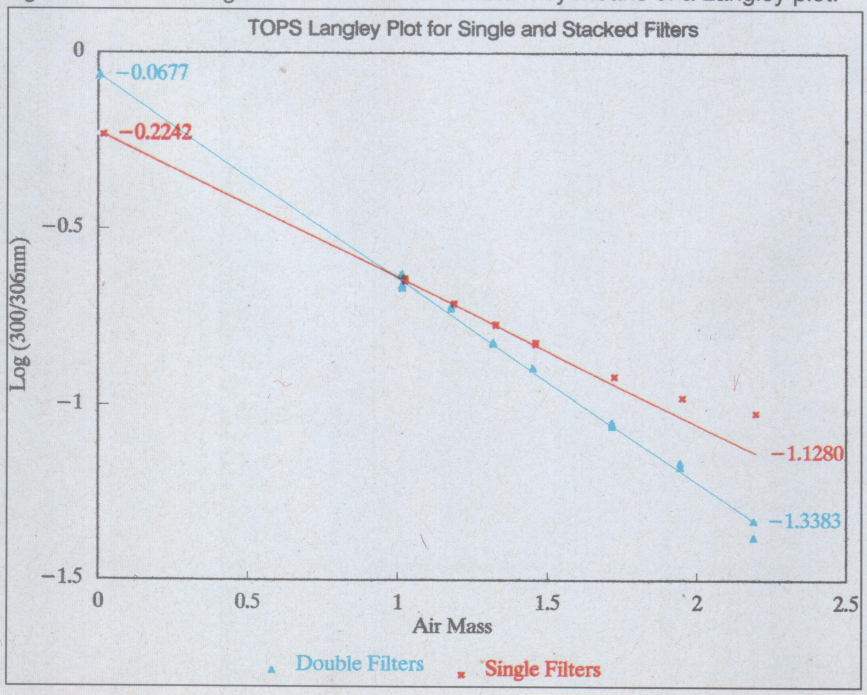
Calibrating TOPS

Several methods can be used to calibrate ozone instruments. The simplest is to compare your observations with those made by a nearby instrument. In the United States, Dobson spectrophotometers are located at Mauna Loa, Hawaii; Fresno, California; Boulder, Colorado; Bismarck, North Dakota; Nashville, Tennessee; Caribou, Maine; and Wallops Island, Virginia. In Canada, ozone instruments are located at Edmonton, Alberta; Churchill, Manitoba; Toronto, Ontario; and Goose Bay, Labrador. You can obtain the daily readings from these and other ozone stations from the World Ozone Data Center. (Address will be sent to SPAN participants; see next page.)

If you are not near a Dobson station, perhaps you can visit a nearby area while on vacation, preferably in June or July when the Sun is highest in the sky. If the ozone is relatively stable, you can make measurements over half a day to simulate a range of Sun angles for different times of the year.

Another method is to compare your readings with those made by satellite. NASA operates a computer bulletin board that gives worldwide measurements of ozone observed by the TOMS instrument aboard Nimbus-7. However, this satellite is rapidly reaching the end of its useful life. Also, various computer problems and calibration difficulties often cause delays of many months in the placement of ozone data on the bulletin board. New ozone monitoring satellites would solve this problem. Meanwhile, for information about obtaining the TOMS data, write the National Space Science Data Center (Goddard Space Flight Center, Code 933.4, Greenbelt, Maryland 20771).

Figure 6. Determining the extraterrestrial constant by means of a Langley plot.



scope slide over them. If you then tilt the slide at a 45° angle, you will see the filters reflected in the slide.

Using TOPS

Before using the instrument, be sure the cabinet is closed and that no light leaks through any openings. If necessary, use black paper to shield the detectors from light leaks. You can also insert tubes over the detector/filter assemblies. In either case, be sure that nothing blocks the sunlight reaching the detector.

To use the instrument, first make sure both amplifiers are zeroed by switching on the power in subdued light or by blocking the apertures. If either readout indicates more than 0, open the case and adjust the appropriate zero potentiometer (R2).

Go outdoors and point the instrument toward the Sun while watching the shadow the upper alignment vane casts on the lower vane. When you see the spot of sunlight on the lower vane, align the instrument until the spot of sunlight is centered over the alignment mark. Hold the instrument securely and, assuming the instrument incorporates readouts with a hold feature, press the readout "Hold" button to save the data.

Operators of Dobson spectrophotometers usually make ozone observations at mid-morning, solar noon and mid-afternoon. Noon measurements are important because that's when the level of solar UV is highest. Also, since the Nimbus-7 satellite is in a Sun-synchronous orbit, it will pass within range of your location within half an hour or so of noon every day.

Make at least three observations per session. Record them in a notebook or read them into a tape recorder and transcribe them later. Be sure to record the standard time. Later, you can use the standard time to determine the correct local apparent time.

After a measurement session, store the instrument in a clean, dust-free spot because dust and deposits from cooking fumes will block UV. **Never store the instrument inside a closed car or car trunk on a sunny day because high temperatures may alter the wavelength response of the filters.**

The photodiode window and both faces of both filters must be kept meticulously clean. Dust must be blown away with clean compressed air. Especially dirty filters can be cleaned with a drop of camera lens cleaner fluid and lens cleaning tis-

sue. The film left behind should then be removed with a drop of methyl alcohol and lens cleaning tissue.

Modifying TOPS

There are many ways to modify the basic TOPS design. One is to save money by using only one digital readout; a selector switch would permit the signal from each detector to be sampled sequentially. However, this method is not satisfactory when making observations through thin clouds or cloud haze and especially when the Sun peeks out from behind clouds for only a second or so.

Another modification is to eliminate the readouts and connect the amplifier outputs to a computer by means of an analog-to-digital (A/D) conversion board, as Eric and I have done. Many A/D boards come with software that will permit you to select how often the computer samples the detectors. Or you can do as we did and write your own software. See ads in electronics and computer magazines.

An advantage of a computer is that you can insert a program that automatically computes the ozone amount within milliseconds of each observation. Both channels of UV data and the ozone measurements can then be displayed or printed out and saved on a disk. In any case, it is very important that the instrument be properly pointed at the Sun when the computer is taking data. ✳

PARTS LIST

(One of two channels)

B1 — Miniature 6-volt (23-469) or 7-volt (23-601) battery
C1 — 100 pF capacitor (272-123)
C2 — 0.01 uF (272-131)
D1-D3 — 1N914 diode (276-1122)
DPM — Digital Panel Meter (see text)
F1 — Ultraviolet filter (see text)
IC1 — TLC271CP (Texas Instruments; see text)
J1 — 1/8" phone jack (274-249, 274-250 or 274-248)
P1 — 1/8" phone plug (274-286 or 274-287)
PD1 — Photodiode (see text)
R1 — See text
R2 — 100K trimmer potentiometer (see text)
R3,R4 — 1M resistor (271-059)
S1,S2 — SPST miniature toggle switch (275-624)
S3 — Normally open push-button switch (275-1571)
S4 — SPDT miniature toggle switch (275-625)

Miscellaneous — Perforated or etched circuit board, enclosure and alignment vanes (see text), battery holder (270-405), filter holder, wire and solder.

(Numbers in parentheses are Radio Shack 1992 catalog numbers.)

SPAN Ultraviolet Filters

The Science Probe Atmospheric Network (SPAN) is looking for dedicated ozone and UV-B observers. However, ozone and UV-B measurements by different instruments are not always consistent. The best way to provide consistent measurements is for all instruments in the network to use filters from the same manufacturing run.

SPAN is now working with a major filter manufacturer to determine the best specifications for filters suitable for use with TOPS instruments.

If you are seriously interested in purchasing one or more pairs of such filters together with suitable high-resistance feedback resistors, send a self-addressed, stamped business-size envelope to SPAN, P.O. Box 11250, Fort Worth, Texas 76110. Include a typed or neatly printed letter with your name, affiliation, address and phone number, and state your level of interest. **Do not send money.**

If sufficient inquiries are received, SPAN will arrange for a production run of identical filters. Depending on the number of participants, the cost of a pair of filters and resistors should be under $150, including shipping, handling and a nominal registration fee.

SPAN is also looking into the possibility of manufacturing ozone- and UV-monitoring instruments. If you are SERIOUSLY interested in more information on obtaining a pre-built, calibrated instrument, please note this in your letter.

FURTHER READING

For additional information about the design of filter instruments for measuring solar UV, see "How to Monitor Ultraviolet Radiation from the Sun" by Forrest M. Mims, III in "The Amateur Scientist" department of *Scientific American* (August 1990, pp. 106-109). Basic electronic construction tips can be found in *Getting Started in Electronics* by Forrest M. Mims, III (Radio Shack, 1983).

Among the scientific papers on filter ozonometers that proved helpful in the development of the TOPS instruments are these:

"Agreement Between Dobson Spectrophotometer and Filter Ozonometer Measurements of Total Ozone" by W.A. Matthews in *Journal of Applied Meteorology* (vol. 11, Feb. 1972, pp. 239-241).

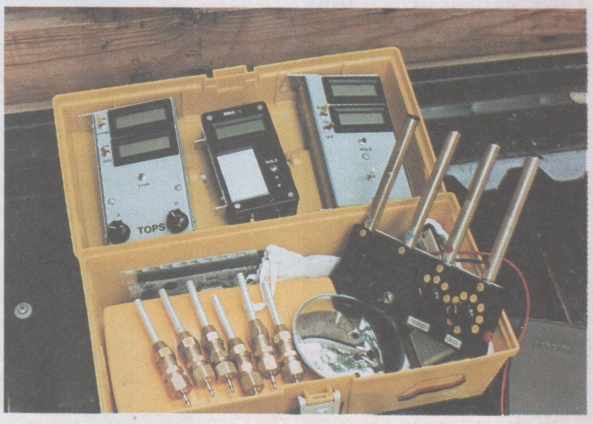
"Problems in the Use of Interference Filters for Spectrophotometric Determination of Total Ozone" by R.E. Basher and W.A. Matthews in *Journal of Applied Meteorology* (vol. 16, Aug. 1977, pp. 795-802).

"The Effect of Bandwidth on Filter Instrument Total Ozone Accuracy" by R.E. Basher in *Journal of Applied Meteorology* (vol. 16, Aug. 1977, pp. 803-811).

For information about determining local apparent time and the equation of time, see *Sundials and Their Construction* by Albert E. Waugh (Dover, 1973) and various books about astronomy.

Acknowledgments

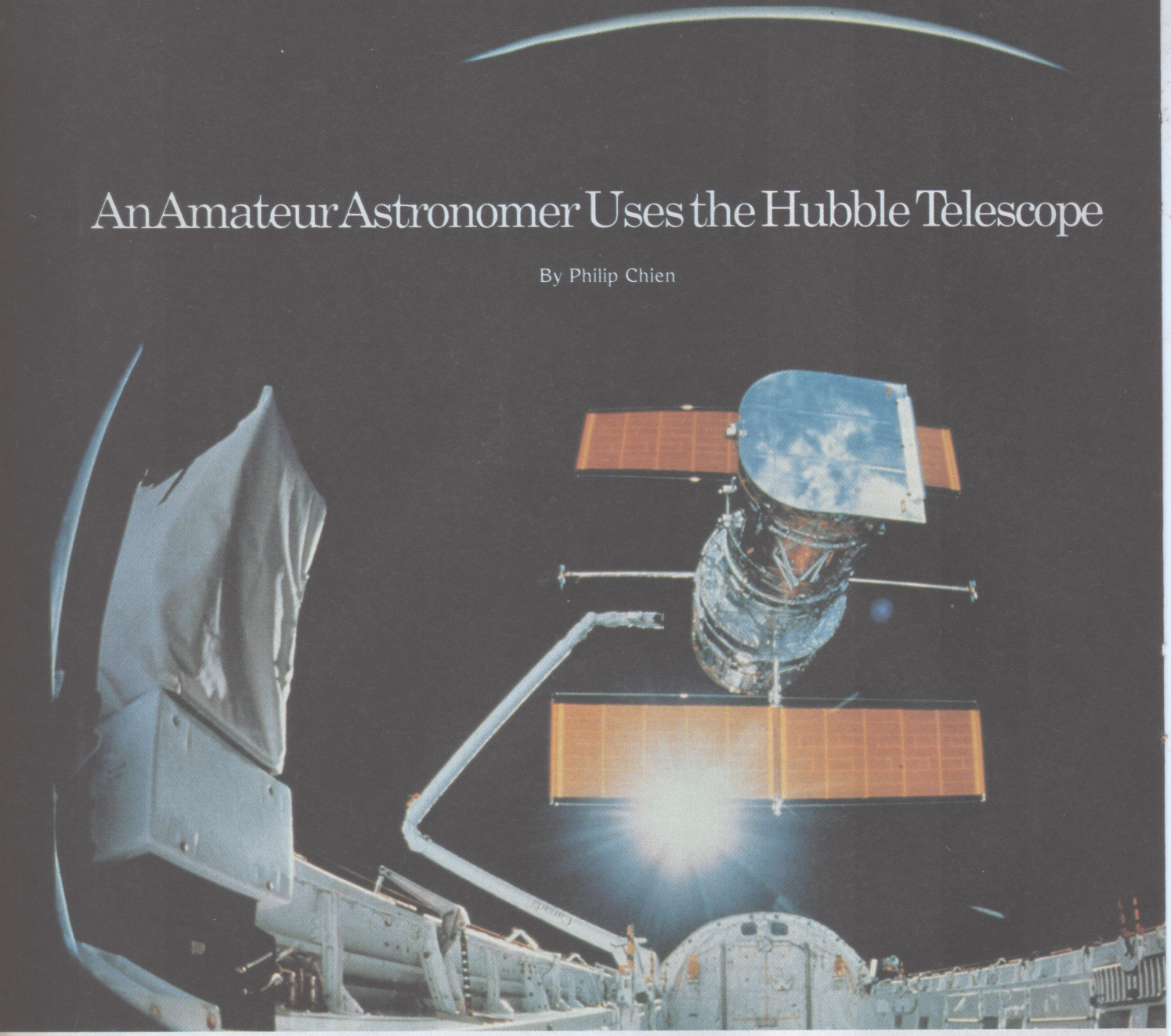
Development of the TOPS instruments would not have been possible without the advice and encouragement of Arlin J. Krueger of NASA's Goddard Space Flight Center. Dr. Krueger provided ozone data from the TOMS instrument aboard the Nimbus-7 satellite that made possible early verification of the accuracy of the TOPS instruments. I am also indebted to Walter Komhyr and John DeLuisi of NOAA for helpful advice and to Robert Grass of NOAA for spending two days comparing TOPS-1 and TOPS-2 with Dobson-65, the World Secondary Standard Dobson Spectrophotometer. The filters for the TOPS ozonometers were provided by Barr Associates.



Shown here in the back of his pickup truck during a field trip are some of the instruments Forrest Mims has designed to measure the ozone, water vapor and oxygen in a column through the atmosphere. The two light blue instruments with dual digital readouts are the TOPS ozonometers described in this article.

An Amateur Astronomer Uses the Hubble Telescope

By Philip Chien



Summary

Jim Secosky was the first amateur astronomer to share Hubble telescope time with the pros. Philip Chien takes you along on a Science PROBE! field trip to observe the first amateur project completed with the giant telescope: an analysis of the unexplained brightening of Jupiter's moon Io.

Amateur scientists have made valuable contributions in many fields, especially astronomy. Although there are 5,000 professional astronomers worldwide, they don't have the time or the telescopes necessary to continuously monitor the entire sky.

That is why the 300,000 amateur astronomers in the United States, and hundreds of thousands more in other countries, are so important.

Besides making their own observations, amateurs assist professional astronomers by monitoring several types of stellar objects, especially ones that change over time. Variable stars, newly discovered objects and changes in planetary surfaces are all observed on a regular basis by amateurs using backyard telescopes.

Supernova 1987A, the brightest Supernova in 400 years, was discovered almost simultaneously by amateurs in Africa and Australia and a professional astronomer in Chile. Within days every observatory in the Southern hemisphere, and some in orbit, were carefully measuring SN 1987A's output as it quickly brightened.

The First Hubble Amateur

In recognition of the vital role played by amateur astronomers, Riccardo Giacconi, the director of the Space Telescope Science Institute (STScI), graciously granted observing time on the Hubble Space Telescope to several amateurs who proposed projects with

First Hubble Amateurs

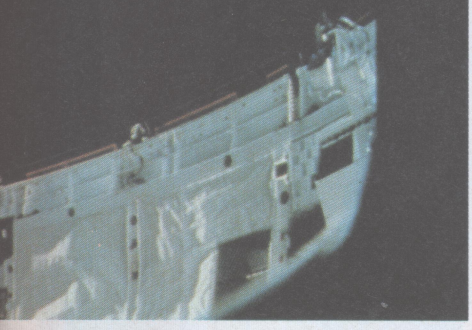
Jim Secosky, a science teacher at Bloomfield Central school near Rochester, New York, is looking for evidence of frost forming on the moon Io as it travels into Jupiter's frigid shadow.

Ray E. Sterner, a computer scientist at Johns Hopkins University's Applied Physics Lab, wants to study mysterious luminescent arcs recently discovered in a distant galaxy cluster.

T. John Hewitt, an employee of the Lawrence Hall of Science Museum in Berkeley, California, wants to use an explosive stellar nova as a sort of gigantic "flashbulb" to ionize material near the star and search for a shell of comet nuclei.

Peter Kandefer, a consultant and electronics engineer, will use HST's High Resolution Spectrometer and High Speed Photometer to study in detail light fluctuations and turbulence in the atmospheric structure of a peculiar variable star.

Ana M. Larson, a Seattle mother who recently returned to school at the University of Washington, plans to use HST to hunt for massive protoplanets forming in a nearby region of star birth.





© Earth News

Left: Hubble's release from the shuttle. Above: Observational astronomer Helen Hart, principal investigator James Secosky, and science operations specialist Karl Whittenburg.

significant scientific merit. On April 20, 1992, Jim Secosky became the first amateur astronomer to control the $1.5-billion observatory.

When I arrived at the STScI at 3 a.m. that morning, the sky was overcast, and there was a possibility of rain. Of course this atmospheric barrier would not affect Secosky's observations, because Hubble is in orbit far above the clouds.

I was introduced to Jim Secosky and the scientists who would help him perform his observation: Helen Hart, an observational astronomer, and Karl Whittenburg, a science operations specialist.

Io is one of the four Jovian moons discovered by Galileo when he pointed his first crude telescope at Jupiter in 1610. It's the closest large satellite to Jupiter, residing within the giant planet's radiation and magnetic fields. With a diameter of 3,630 km, Io is slightly larger than the Earth's moon. Little was known about Io until the close-up observations of *Pioneer 10* in 1973 and *Pioneer 11* in 1974, followed by *Voyager 1* and *2* five years later.

Hubble's five science instruments have many different capabilities. Secosky's experiment required that the Wide Field Planetary Camera (WF/PC) be operated in its Planetary Camera mode. WF/PC includes 48 special filters, gratings and polarizers mounted on a carousel. The filters permit astronomers to examine concentrations of chemical species by studying spectral emissions. Filter F368M, for example, transmits in the ultraviolet at 3680 Ångstroms, a wavelength that permits sulfur dioxide to be detected. Because Secosky wants to determine if sulfur dioxide is released when Io leaves Jupiter's frigid shadow, this filter would prove crucial to his experiment.

The Planetary Camera has a focal ratio of *f*/30, a field of view of 1.15 arc-minutes, and a resolution of 0.043 arc-seconds per pixel. These specifications provide an image of Io approximately 22 pixels across.

As Hubble traveled around the Earth, its computers kept track of the commands necessary for Secosky's observations. Solar system objects are particularly challenging. As Hubble's orbit varies, the targeting parameters change and, as the target moves through the sky new guide stars have to be chosen.

The telescope's gyros pointed Hubble at Jupiter in the constellation Leo, and a set of guide stars was used to position Jupiter and Io precisely within the planetary camera's thumbnail-size detector array.

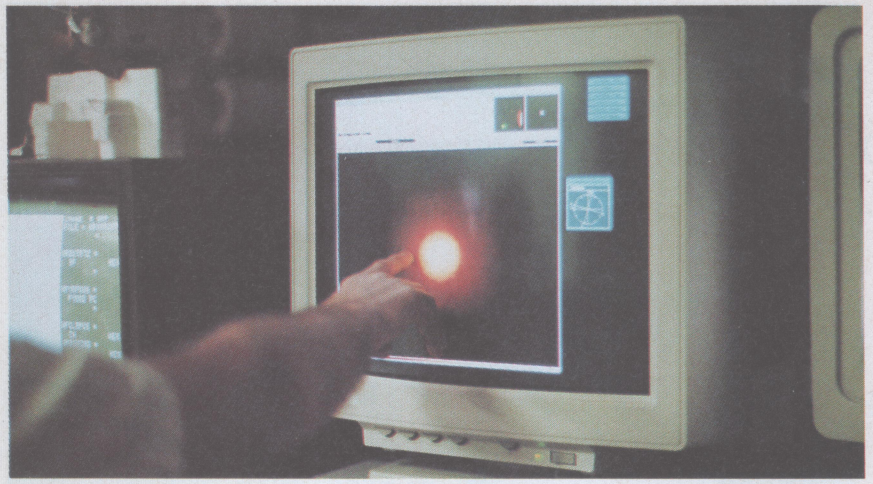
To enhance the quality of the data, the Hubble team instructed the observatory to move slightly to position Io better within the detector's field of view. At this point Io was 715 million km (4.78 astronomical units) from Earth.

As Hubble passed over Indonesia on its 10,832nd orbit, the planetary camera quickly took five images of Io, one with a clear filter, three with the sulfur dioxide filter, and a final image with the clear filter.

The data was sent from Hubble through a relay satellite south of Hawaii to a NASA ground station at White Sands, New Mexico; another relay through a commercial communications satellite to the Goddard Spaceflight Center near Washington, DC; and finally to STScI via dedicated lines. The process takes less time than it takes to read about it.

Karl Whittenburg displayed the data on his monitor, and we quickly saw a bright white circle on the screen — success!

Even though it was raw, uncalibrated data, it was clear that Secosky had good information. The



Jim Secosky examines a false-color image of Io.

team experimented with the data, adjusting the brightness and contrast to bring out surface features.

Even at its closest approach to the Earth, Io is still an extremely small object, and each pixel in the image represented 165 kilometers of Io's surface.

Though this was not enough to resolve surface details, it should be adequate for testing Secosky's hypothesis. If he is right, then more sulfur dioxide gas should be revealed in subsequent images of Io as the moon leaves Jupiter's shadow and begins to warm.

Whittenburg and Hart used their workstations to experiment with the raw data, using false color maps to bring out details and compare the earliest and latest exposures. A quick estimate showed that Io had decreased in brightness approximately 2% between the first and last images.

After the observation was complete Secosky called several friends. An 80-year-old aunt was nonplused, but still understood his enthusiasm. When she was born, the solar system only had eight known planets.

Secosky spent an additional several days working with the data after the technicians at the STScI calibrated the data and put it through computer deconvolution routines. Did he determine whether or not Io's brightening is caused by sulfur dioxide frost? Well, he still needs to analyze his data from two additional sets of observations, but the data have already shown some unexpected results, including the possibility of an erupting volcano.

More Hubble Amateurs

The Hubble Space Telescope is the world's most sophisticated optical observatory. In ultraviolet wavelengths, it is unsurpassed and will always be more capable than any ground-based telescope. And for most targets, it is much more capable than ground based observatories — even with its well-publicized problems. Before Hubble's launch, professional astronomers submitted nine times as many proposals as there was time available for observations. More than 1,000 were granted observation time for Hubble's first year of observations.

For an astronomer's proposal to be selected, it must meet the same qualifications as professional proposals: It must be feasible within Hubble's capabilities, and it must be something that can *only* be performed with Hubble.

In the first round of proposals, received even before Hubble's launch, five amateur proposals were accepted out of 200 applications. Each was allotted a couple of hours, approximately 1% of Hubble's valuable viewing schedule.

Amateur astronomers with accepted projects are treated the same as professional astronomers. They get the same priority for their projects, exclusive access to the data from their observations for one year, and assistance from the scientists and engineers at STScI.

After the discovery of Hubble's spherical aberration and other problems, an assessment was made of all the proposed Hubble observations, including those of the amateurs. Most of the observations could still be performed, although they would require longer exposure and computer processing times to compensate for the spherical aberration.

Some projects that pushed Hubble's technology to the limits of its performance could not be performed. Amateur scientist Ana Larson's search for extra-solar system protoplanets could not be conducted because of HST's inability to resolve extremely dim objects. Ray Sterner's observations were changed from the Faint Object Camera to the Wide Field camera. Sterner's case illustrates why Hubble can continue to produce useful science even with its problems. Hubble's collection of scientific instruments have overlapping capabilities. While some of the projects originally planned cannot be performed, Hubble is versatile enough to complete most observations.

For the first cycle of observations, more than 100 sets of data have already been collected. For the second round of observations, 130 professional proposals have been accepted, all viable within Hubble's current limitations. In addition, it is anticipated that three to five amateur proposals will be selected.

And next time? The third round of amateur proposals is under way. To obtain an application, send a letter with your name and address requesting a Hubble Amateur proposal kit to the American Association of Variable Star Observers (AAVSO) 25 Birch St., Cambridge, Massachusetts 02138, Attn.: Janet Mattei. ✳

FURTHER READING

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Wanderers in Space by Kenneth R. Lang, Charles A. Whitney (Cambridge University Press, 1991).

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ABOUT THE AUTHOR

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Growing *Bigger* Crystals Automatically



Photos and Text by James Bailey

Important: This project is for advanced experimenters only. Before attempting this project, read "Before You Begin Construction" at the end of this article.

Summary

Controlling the temperature and evaporation rate of a crystal-growing solution is crucial to producing large, high-quality crystals of various salts. The amateur scientist can build a system to automatically control the temperature of a crystal-growing solution and agitate the solution for satisfactory crystal formation.

Thousands of hobbyists "grow" their own crystals of water-soluble salts to use in experiments or to just enjoy the intrinsic beauty of crystals.

The process of making such crystals is remarkably simple. You add a water-soluble salt to distilled water until a saturated solution (one in which all the desired salt the solution can hold has been dissolved) is made. A small crystal or fragment of one (called the *seed*) is suspended in the solution. As the water evaporates, the solution becomes supersaturated (holds more salt than it can easily keep in solution). The excess salt leaves the solution and deposits on the seed, causing it to grow.

A variation of this method is to make the saturated solution with heated water — which becomes supersaturated as it cools.

While both methods are simple, they do not always yield satisfactory results. It's best if the solution is exactly at saturation or slightly supersaturated when you add the seed. If you put in the seed before saturation, it dissolves and you lose it. If you wait until the solution is highly supersaturated, the crystal grows too fast, resulting in misshapen, cloudy, or stray parasite crystals.

To eliminate these problems you must control both the temperature and evaporation rates of the solutions. Controlling the temperature lets you bring a solution to saturation and keep it there; covering the solution lets you slow or stop the evaporation of the water.

This article tells you how to build your own system, using readily-available parts.

Important Safety Requirements

Use only Pyrex containers for these experiments. A number of years ago, I tried a so-called "battery jar" for my first attempts at growing larger crystals. The glassware vendor I bought it from had the audacity to send me what appeared to be an ordinary gallon jug with the top cut off. To make a long, sad story short, the "jug" cracked and two liters of precious chemicals soaked the lamp, the bench, and all the wiring.

The controller should be plugged into an isolation transformer. This will minimize the shock hazard if you suffer a solution spill like I did. An alternative is to plug the controller into a ground fault breaker. *Never* operate the controller without taking one of these precautions — using both is best.

Don't substitute an "indoor" flood lamp for the weatherproof one specified. The specified lamp will survive many small water drips. An indoor one will shatter!

As for the chemicals, most salts suitable for crystal growing are at least somewhat toxic. They can also be corrosive to metal objects. Nickel salts can cause allergic reactions in some people. Wash your hands thoroughly after handling any chemicals.

Keep your equipment and all chemicals safely out of reach of children! Warm nickel sulfate solution has a slightly sweet smell that may tempt a youngster to sample it, especially with its lovely emerald green color.

Finally, don't let your solutions cool to room temperature in your glass containers unattended. Crystals are poor conductors of heat. Large masses on the bottom of the container will make it difficult to reheat the solution to redissolve the salts. The resulting thermal difference across the bottom of the container could cause it to crack.

When shutting down the system, pour the warm solution into a plastic container. Stir or shake the solution a few times as it cools — this will cause small crystals to form. This makes the chemicals easier to reuse.

Overview

Figure 1 (next page) shows the three main sections of the system. The heating element is a 150-watt outdoor flood lamp mounted inside an enclosure made of wire mesh. The Pyrex® container with the crystal growing solution is surrounded by an insulating jacket and placed atop the heating element.

Above: A fast-growing Rochelle salt crystal.

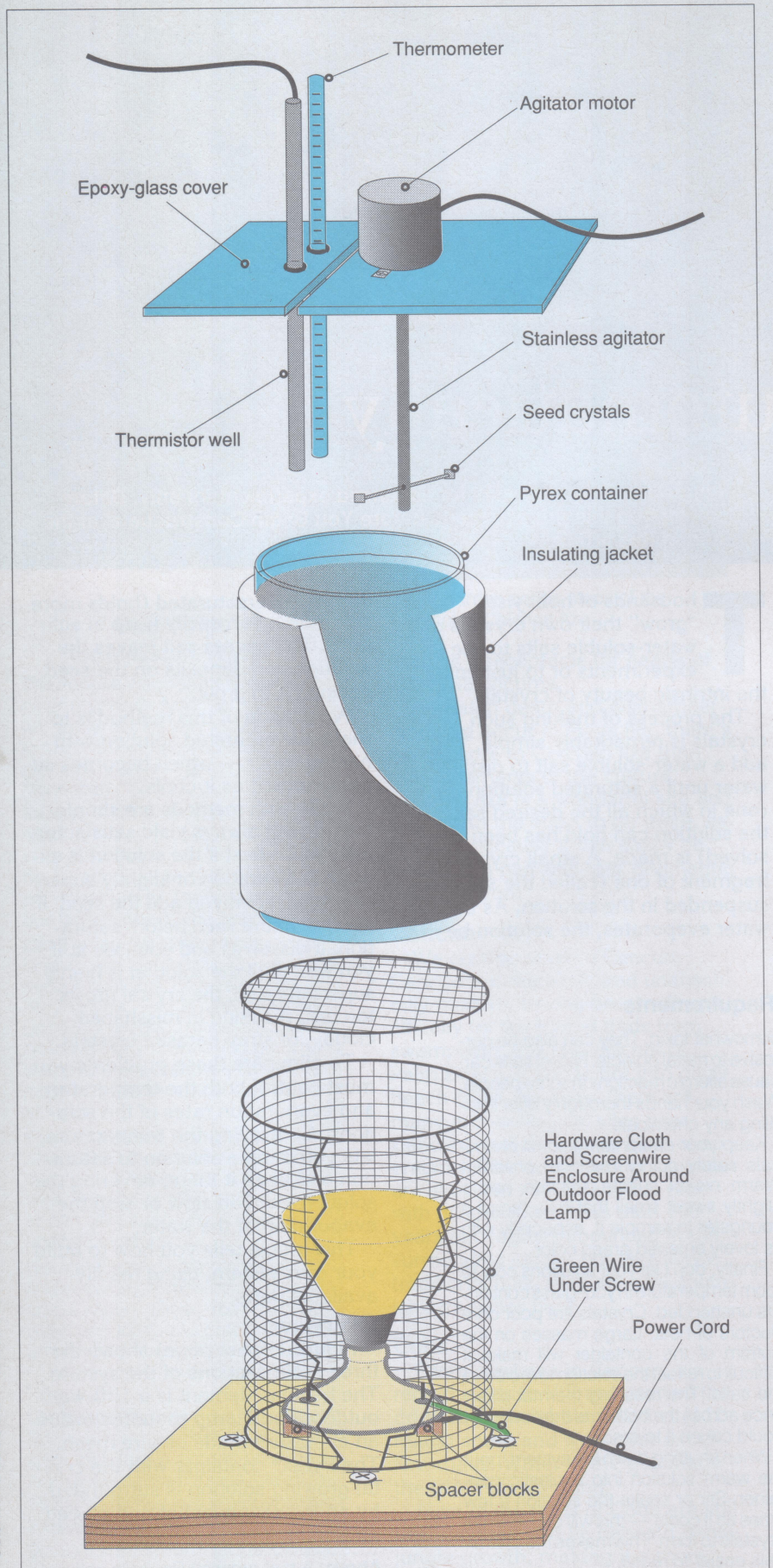


Figure 1 (left). The three major parts of the crystal-growing system.

The container is covered by a two-piece epoxy-glass board on which an agitator motor, thermometer and thermistor are mounted. The cover is made in two pieces so the agitator motor and shaft can be removed without disturbing the thermistor. The agitator serves two purposes: It gently stirs the solution so it remains uniform in temperature and moves your seed crystals so they are constantly in contact with fresh, saturated solution. Both functions help ensure optimum crystal growth.

The Container

You'll need a wide-mouth Pyrex container with a capacity of at least 2 liters (2 quarts). I used a 6-inch diameter "animal jar." (This can be expensive, but you can use a 2-liter beaker, or a 12-cup coffee maker pitcher instead.) The heating element enclosure needs to fit nicely under this container.

Building the Heating Element Enclosure

Cut rectangular and round pieces of hardware cloth as shown in Figures 3 and 4. **Be sure to wear sturdy gloves to protect your hands when working with this material.** The cut edges scratch terribly. Leave the cut wires long on the edge opposite the tabs; you'll need them for attaching the top. Cut the wire ends flush on the tab side. Roll the rectangular piece into a cylinder about 16 centimeters (6.5 inches) in diameter. Overlap one square on each end. Clamp the ends temporarily and solder the



Figure 2 (above). Raise the lamp socket on 2 to 3 cm (¾ to 1") wood blocks to make room for the wiring and to move the lamp closer to the top of the enclosure.

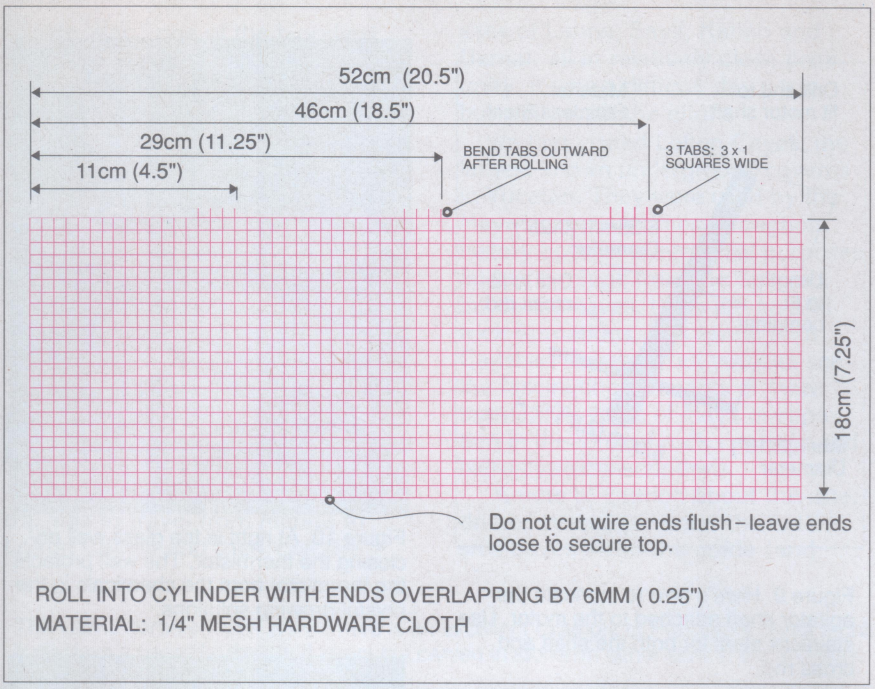


Figure 3. Dimensions of hardware cloth for Heating Element Enclosure.

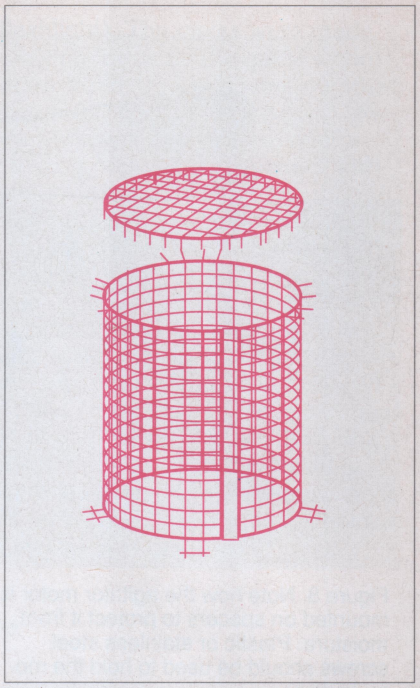


Figure 5. How the Heating Element Enclosure fits together.

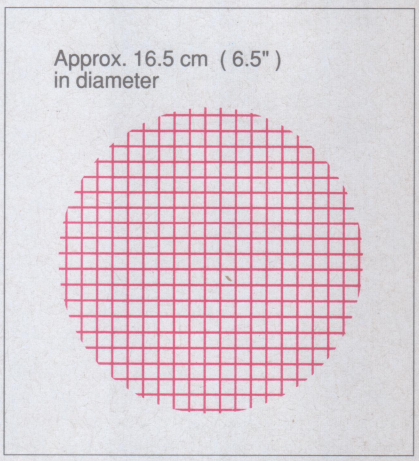


Figure 4. Top piece for Heating Element Enclosure.

overlapping edges together. Now bend the tabs outward.

Cut a piece of metal window screening the same size and use it to line the inside of the cylinder. The screening won't solder. Just secure it by threading some fine wire through the mesh here and there.

Line the circular top piece of hardware cloth with screen the same way. Attach the top to the cylinder, screen inward, by bending the cylinder's wire ends into hooks after pressing the top down over them. (See Figure 5.)

Cut a 45-cm (18 in.) length from a 6-foot, three-wire power cord (the part with the plug will be used later). Attach the black and white leads to the lamp socket. Mount the lamp socket to the wood base with two #8 or #10 round head wood screws. **Be sure to add the 2- to 3-cm (¾ to 1 in.) wood spacers under the lamp as shown in Figure 2.**

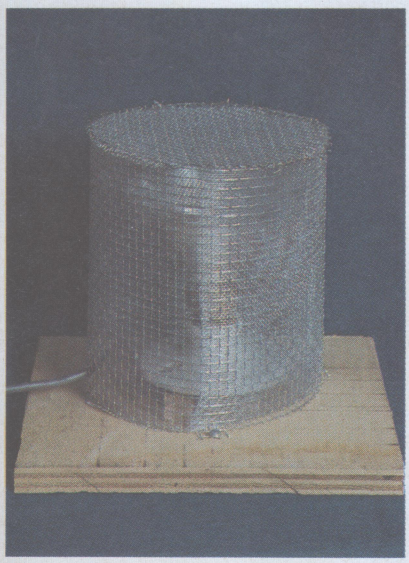


Figure 6. Finished Heating Element Enclosure.

Cut or spread a 12.5-mm (½ in.) hole in the side of the screen as shown for the cord. Press a 12.5-mm (½ in.) rubber grommet into this hole to protect the cord. Install the reflector lamp. Thread the end of the 3-wire cord through the grommet. Place the enclosure down over the lamp and fasten with #6 pan head sheet metal screws down through the tabs and into the wood base. **Before tightening the screws, wrap the end of the green wire around one screw so it will make good contact with the screen.** *CAUTION: The green wire provides a safety ground for the enclosure, and must be attached as shown.* You'll connect the free end of the cord to the controller box later on.

Use an epoxy-glass electronics circuit board for the cover. You *must* remove the copper coating from this board (or, position the board so the copper side is away from the solution when in place). Do not use styrene plastic for the holder — it will warp from heat.

Drill an 8-mm (5/16 in.) hole in the center of the board. Cut the board into two pieces as shown in Figure 7. Use the agitator motor as a template to mark mounting holes. Drill holes as required and mount

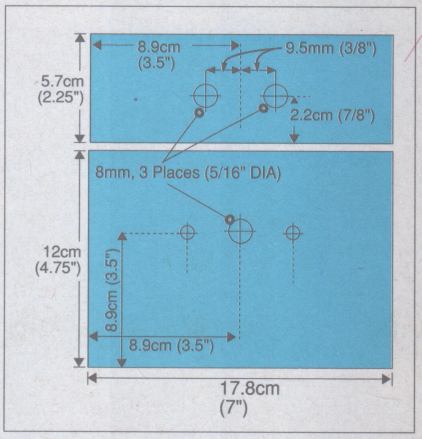


Figure 7. Container cover, showing drill holes and dimensions.

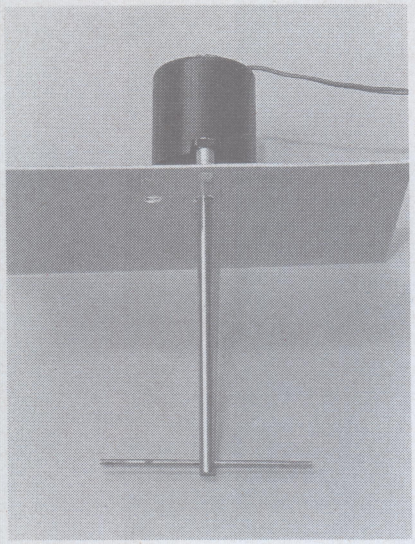


Figure 8. Note how the agitator motor is mounted on spacers to protect it from moisture. Plastic or stainless steel screws should be used to hold the motor in place.

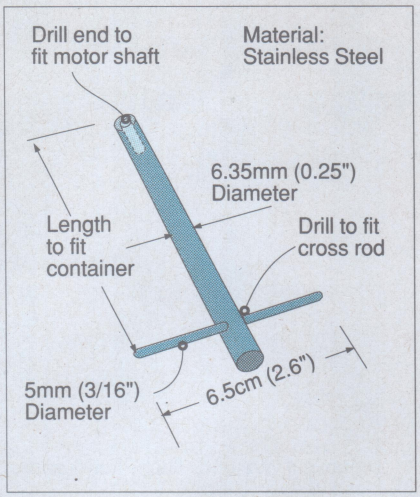


Figure 9. Here's how to fabricate the agitator shaft attached to the motor. Use stainless steel for both the shaft and cross rod.

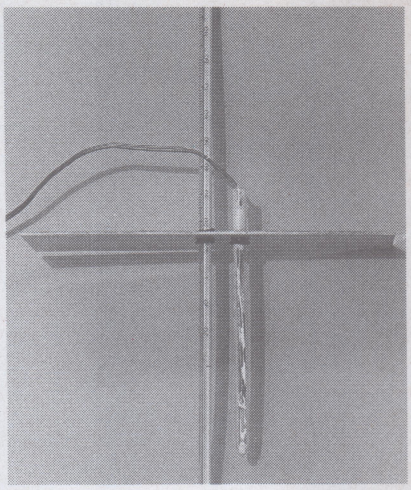


Figure 10. At right is the glass well enclosing the thermistor. The well protects the thermistor from the chemicals in the crystal-growing solutions.

with plastic or stainless steel screws. I used #4-40 threaded spacers to protect it from moisture. See Figure 8. I also added an O-ring around the shaft, between the cover and the motor, to give additional moisture protection.

NOTE: The power source for the motor will depend on the type used.

Refer to Figure 9 for details on the agitator-seed support. The shaft should be long enough to reach to within 2.5 cm (1 in.) of the bottom of the Pyrex container. Attach the support to the motor shaft with "instant glue" or a set screw. The agitator motor I used is a 4.5-volt DC motor providing 30 revolutions per minute; this motor is available from Hankscraft (see Supplies and Parts Sources at the end of this article). I'm operating my motor at 3 volts from a pair of AA cells; it will run for weeks from that pair. The exact motor speed or type is relatively unimportant as long as the speed isn't too high.

In the other piece of the board, drill two 8 mm ($^5/_{16}$ in.) holes. One is for a thermometer, and the other is for a glass well containing the thermistor. Make the well by melting one end of 6 to 8 mm (approx. ¼ in.) outside diameter (OD) glass tubing until it closes. "Fire polish" the open end by rotating it in the flame of a propane torch. The thermistor well can be from 12- to 22-cm (4¾ to 9 in.) long. Position it so that it is about midway into the solution and isn't bumped by the agitator or growing crystals. Use two "O" rings to support the well and thermometer on the board. Attach flexible, insulated leads to the thermistor and coat it liberally with "heat sink" grease (available at many electronics suppliers). Carefully thread the thermistor all the way to the bottom of the well. Figure 10 shows details of the finished section. Be sure to push the thermometer far enough through the board so it is not top heavy. If necessary, add some weight to the board.

You'll need an insulating "jacket" to fit around the jar. A good way to make one is to cut a sheet of thin urethane foam (approximately 6 mm [¼ in.] thick). Make it large enough to wrap around the Pyrex container you're using. It should not reach all the way to the bottom of the jar (leave about 6 mm [¼ in.] uncovered). Secure with string or ribbon — not tape; you'll need to remove the insulation from time to time to inspect your crystals.

Assembling the Controller

Refer to Figure 13 for a schematic of the controller circuit. I built it on a perforated circuit board and installed it inside a standard 4x4 in. plastic electrical box. Parts layout and construction is non-critical with the exception of the triac, Q1. The triac *must* be enclosed within the box so that it is impossible to accidentally touch the triac or its mounting hardware. Be sure to use a triac with an electrically isolated mounting tab or stud. No heatsink is necessary for the triac, because the load is only 150 watts.

Testing for Saturation

How can you tell if a solution has reached supersaturation before adding a seed? Place a light behind the jar of solution you want to test. Suspend a low-quality seed in the solution. Examine the seed carefully against the light. If "syrupy" currents can be seen drifting downward from the seed, the seed is dissolving, meaning the solution is not saturated. Remove the seed and let the solution cool further.

If there are no currents, or if the currents are rising slightly, the solution is saturated. You can remove the test seed and replace it with a good one.

If the currents are rising quickly, the solution probably is too supersaturated and should be rewarmed. Some salts (such as Rochelle salt) can go into extreme supersaturation if not seeded or disturbed.

Growing Seed Crystals

Heat about 100 milliliters (3 ounces) of distilled water to 40 to 50°C; gradually add a salt until no more dissolves. Press a small flat-bottomed glass (not plastic) dish into a hole in a block of Styrofoam. Preheat the glass dish with hot water. Replace the hot water with the saturated solution. Select six well-formed crystals from your stock container. Drop one or two into the solution and cover with a sheet of glass. In about 30 minutes check to see if the crystals are still there. (Do not disturb the dish or you may cause hundreds of unwanted crystals to form.) If the seeds are still there, you may add the other four. After 10 to 12 hours, pour off the remaining solution and retrieve your seed crystals. Dry them with a tissue and put them away for your future use. Don't be concerned about lopsided seed crystals — they will fill out when they grow in your agitator jar.

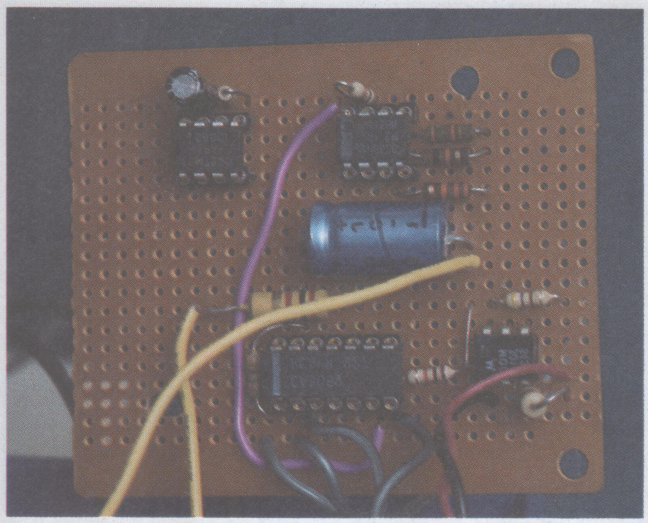


Figure 11. Top view of perforated circuit board showing parts and wire placement.

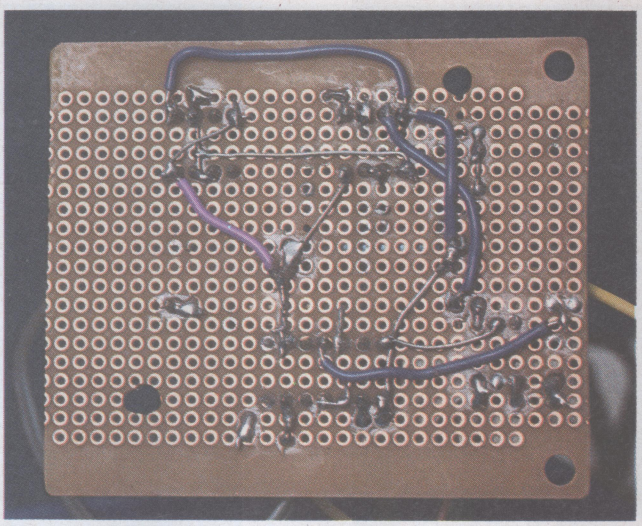


Figure 12. Bottom view of perforated circuit board, showing wire connections and soldering

Refer to Figures 11, 12, 14 and 15 to see how parts are positioned and connected in my unit. *Caution:* Take special care to adequately insulate the AC power wiring (use sleeving on fuse holder). Use a cable clamp for the power cable.

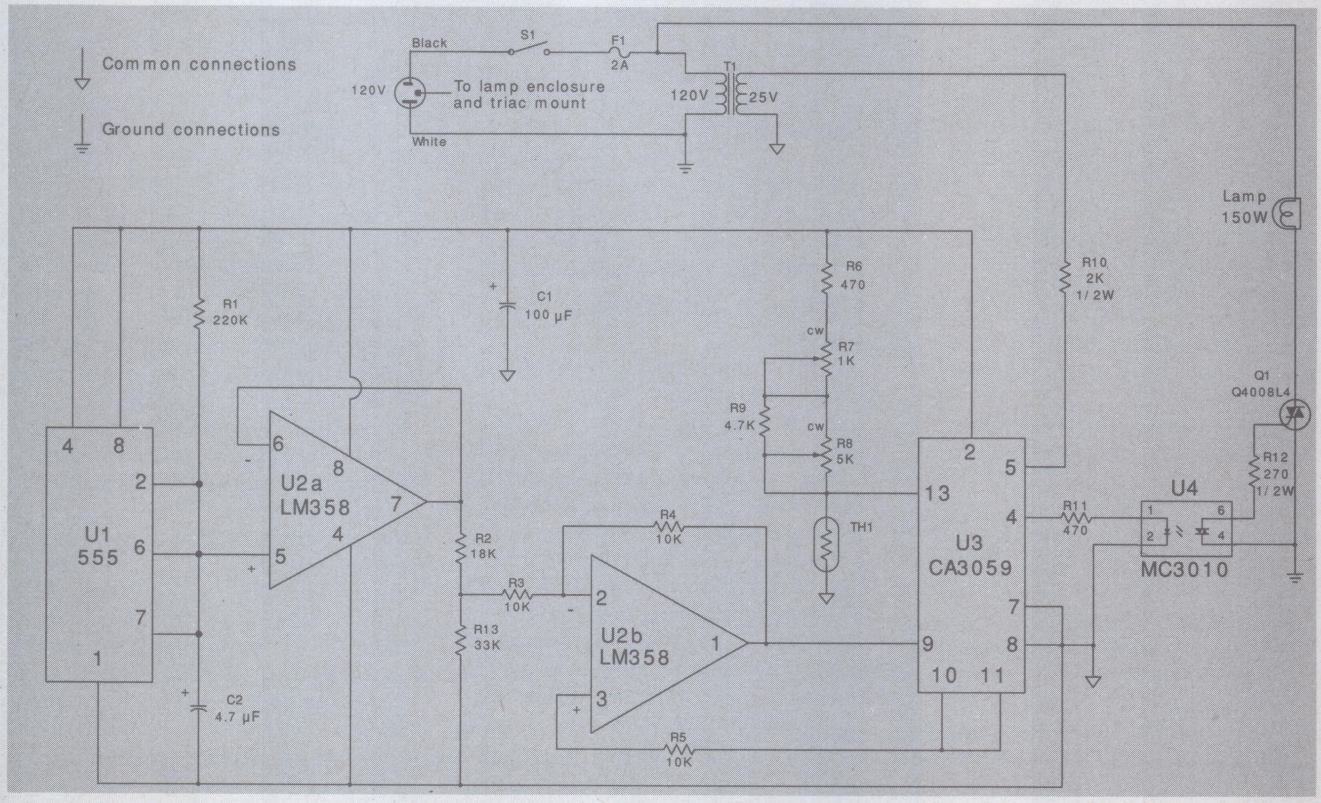
Before mounting the perforated circuit board in the box, have another person double-check your wiring and soldering (often a second pair of eyes will see something you have overlooked). When all is fine, connect the power cord to a source of 120VAC power.

How the Controller Works

Take a look at the schematic diagram (Figure 13) of the controller circuit. Thermistor Th1's resistance increases as the temperature it's exposed to decreases. When Th1's resistance increases enough, it causes U3 (which functions as an AC power controller) to turn on triac Q1 (through the optoisolator U4), which in turn allows current to flow through the lamp. Adjustable resistors R7 and R8 select the temperature at which Q1 turns on. U4 provides a vital safety feature — it isolates the thermistor circuit from the 120-volt power.

Although U3, U4, Q1 and Th1 together could control the solution's temperature, a more precise controller gives clearer crystals. To do this, I added U1, a popular IC often used as a timer or pulse generator. Here it functions as a timer to turn the lamp on and off about twice per second. If Th1's resistance increases even a tiny bit, it causes the lamp to stay on a little longer and off a little less. This means it takes only a very slight change in the temperature of the crystal-growing solution to cause the controller to begin correcting it.

Figure 13. Schematic of controller



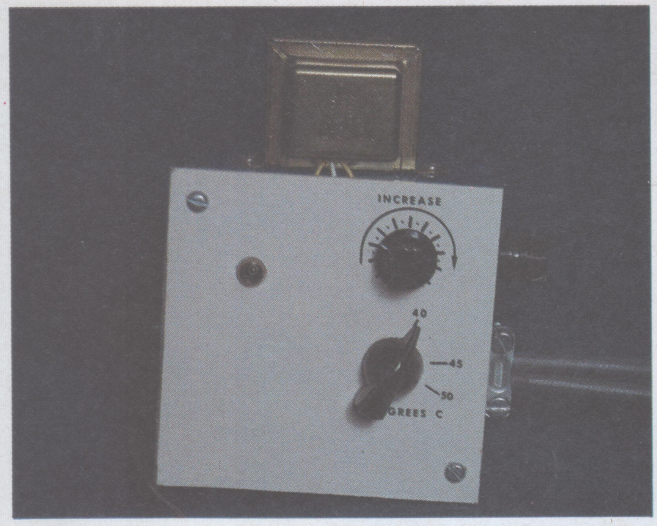


Figure 14. The outside of the controller circuit box. R8 is the lower control, calibrated in 5°C increments, and R7 is the top control.

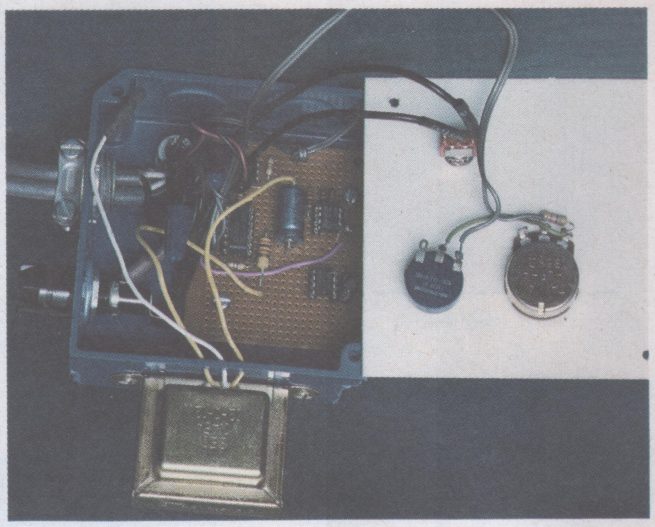


Figure 15. Inside view of the controller box. Note that the fuse holder has insulating sleeving on both connections. The power cord is secured with a cable clamp. The transformer's center tap wire should be cut off or insulated.

You'll need a scale for R7, the 1K potentiometer, before mounting it on the front panel of the enclosure. Rub-on dial markings are best. They can be obtained from such sources as Radio Shack.

Calibrating the Controller

Place the Pyrex jar on the heater assembly. Wrap the insulating jacket around the jar. Fill the jar to within 3-4 cm (a little over 1 in.) of the top with water preheated to about 40°C (104°F). Cover the jar and start the agitator motor. Turn on the controller and set R7 fully clockwise and R8 fully counterclockwise. The heating element lamp should be off. Now turn R8 slowly clockwise until the lamp just starts blinking. Let the system sit for one hour and then note the temperature. If it is less than 40°C, turn R8 slightly clockwise. Once the solution settles at 40°C, mark this point on the panel at the end of the knob's pointer. Turn R8 a bit more in a clockwise direction. The lamp should blink more brightly and stay on longer.

Wait another hour. Then mark the point on the dial where the temperature settles on 45°C (113°F). You'll want marks every 5°C, so repeat this process until the temperature reaches 50° and 55°C. This completes calibration.

Preparing the Solution

Preheat 1.5 liters (about 1.5 quarts) of distilled water to 50°C. Add 2 kilograms (4.4 pounds) of nickel sulfate hexahydrate to the water in increments of about 0.5 kg (1 lb.). Stir continuously while adding the nickel sulfate hexahydrate salt. (If you have access to a magnetic stirrer, use it.) If your stirrer does not have a heater built in, you will need to reheat the solution from time to time.

Once all the salt is dissolved, filter the solution through a Buchner funnel and filter paper to remove debris. Change the paper often, as technical-grade chemicals often contain a lot of debris. (If one is available you can use a side arm flask and vacuum assist to speed the process. I use an old refrigerator compressor as a serviceable vacuum pump.) If you don't have this type of equipment, coffee maker filters work just fine. Use a funnel with inside ribs (for quickest flow).

Or, use an old plastic or stainless coffee filter holder and filters — just be sure to mark this filter holder with a skull and crossbones to remind yourself not to make coffee with it!

Other Crystal-Growing Chemicals

Some other chemicals you might want to try include: Copper sulfate: mix 1315 grams in 2 liters of distilled water at 50°C. Potassium aluminum sulfate (potassium alum): mix 1,068 grams in 3 liters of distilled water at 50°C. Potassium dichromate: mix 1068 grams in 3 liters of distilled water at 50°C. Note: You need not follow the numbers precisely — approximations will do; then allow evaporation, or adjust temperatures to hasten saturation.

Growing Crystals

Set up your controller and heating element in a cool place that has a fairly steady temperature. A steady air temperature will make your crystals grow more perfectly. (A basement area is best. Also, you'll cause less of a problem with spills in the basement!)

Pour the prepared solution into the insulated jar. Put both halves of the cover in place and plug in the controller. If using a beaker, it is best to seal the lip area with cling-type plastic wrap to help prevent evaporation. The cover pieces will seal the rest of the top. Set R8 for 50° and set R7 fully clockwise. Let the solution reach 50°C.

When the thermometer indicates 50°C, remove the insulating jacket and examine the solution against a bright light. If no crystals can be seen on either the agitator, the thermometer, or the well, replace the jacket and reduce the temperature by about one degree by turning R7 counterclockwise by one "mark." Wait until the temperature drops and recheck for crystals. Once crystals begin to form, let them continue to grow for 24 hours. Then turn off the agitator and remove it from the solution. Save a few of the better crystals for seeds.

Rinse the agitator, wipe it dry, and attach a seed to each end of the agitator arm with nylon thread and plastic sleeving as shown in Figure 16. Rinse the shaft again with distilled water to remove any microscopic seeds. Heat the shaft and arm with a hair dryer until it is about the temperature of the crystal-growing solution. A rough guess is okay — it's better to get it too warm than too cool. You want to

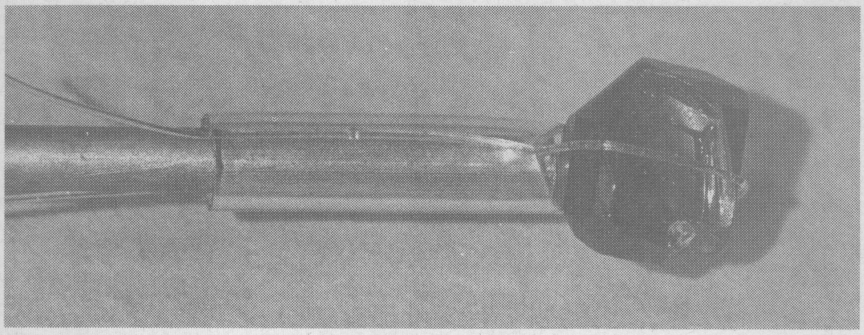


Figure 16. Attach your seed crystal to the agitator cross rod using a length of monofilament fishing line or "invisible" sewing thread. Use a piece of plastic sleeving to secure the thread to the rod.

avoid getting too many stray crystals forming on the agitator.

Replace the agitator and turn it on. After a few hours, remove the insulating jacket and observe your seeds against a bright light. They should have grown somewhat. Replace the jacket. Using R7, reduce the temperature about 1°C per day by turning it counterclockwise one mark. The exact temperature reduction is not too important. However, don't drop the temperature much more than 1°C per day. Otherwise, your crystals will be cloudy or too many stray crystals will form. Continue this process until R7 is completely counterclockwise.

Reset R7 fully clockwise. Check the solution temperature, and reset R8 to the solution temperature. Continue lowering the temperature each day until the solution reaches 35°C, or until your crystals get too large and start to rub against the sides of the container. At this point, turn off the agitator and remove it from the solution. Slip your finished crystals off the agitator shaft and wipe them dry. Don't touch the crystals with your bare fingers — fingerprints can be permanent.

Fine Points

If your seeds or growing crystals pick up stray smaller crystals, pop them off with a sharp tool and put the good parts back in the solution. The holes will repair themselves. You can also use a cleaved section of a crystal for a seed. To protect crystals you want to keep permanently for display, spray them with clear gloss lacquer. This helps keep the water of hydration in and fingerprints off. Some of my specimens are more than 20 years old and are still in perfect condition. ✳

ABOUT THE AUTHOR

James Bailey is a development engineer working in industry and has been awarded nine patents. He has published more than 150 articles about astronomy, electronics, physics, photography and other technologies. He first described how to grow crystals in "The Amateur Scientist" department of *Scientific American.*

Experiments

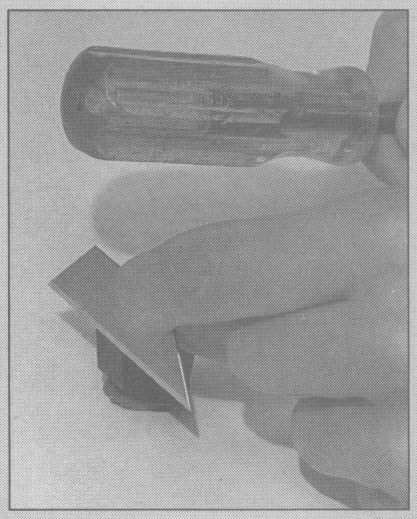
Nickel sulfate hexahydrate is a good material to start with. It's easy to grow crystals over 3 cm (more than 1 in.) in cross-section with it, and you can do some interesting experiments with the finished crystals.

Crystals made with nickel sulfate hexahydrate are fairly easy to cleave. Cleaving a crystal means to cut it parallel to one of its crystallographic axes. Cleaving isn't the same thing as sawing a crystal. Instead, cleaving means cleanly splitting a crystal by placing a razor blade or sharp hobby knife at the right place on the crystal and giving it a rap with the handle of a screwdriver or similar tool. Not all crystals have this property, and it takes a bit of practice to consistently cleave crystals.

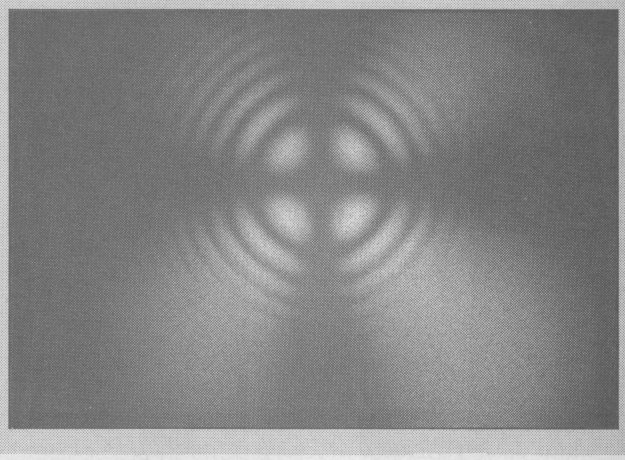
To cleave a crystal, select a good single crystal. (Stray crystals interrupt the cleavage planes.) Press the crystal into a wad of modeling clay or similar mounting media. Position the crystal so a square face is vertical and to one side. Place the blade on top of the crystal exactly parallel to the square face and about 1.5 mm ($1/16$ in.) in from the face. Give the blade a rap. The face should pop off cleanly. Keep trying until you get few good ones. You may have to sacrifice a couple of crystals before you get the knack.

Avoid touching the cleaved surfaces so you don't fingerprint them. These cleavages are useful for seeds and for other experiments.

A striking optical feature of certain types of crystals is their interference figures. They are beautiful patterns that can be seen through cleaved sections of some crystals when viewed through crossed polarizers. To see them through your nickel sulfate cleavages, place a clear cleaved section in the middle of one sheet of polarizing film. Place a second sheet on top of the section and rotate the film until the film below goes dark. Hold the sandwich up to your eye and look through (not at) the crystal against a diffuse light. You should see a crosshatch and circle pattern similar to an anti-aircraft gunsight. This is the interference figure. To see the figure even better, place a short focal length lens on top of the sandwich and look through the lens. You can view the figure from a more comfortable distance this way.



(Above) To cleave a crystal, mount it to the table with a bit of modeling clay or florist's putty. Place a sharp blade parallel to the cleavage plane, and then give the blade a sharp rap.



(Right) Axial interference figures seen through a cleaved section of nickel sulfate crystal.

Before You Begin Construction

This project is for advanced experimenters only! You should have experience with building electronics circuits and making electrical connections before attempting to build this project.

If you have not successfully built projects of similar complexity in the past, you should seek the assistance of qualified persons during the construction of this project. In particular, you should not try to build this project if you're under 18 years of age unless it is under the direct supervision of a qualified adult, such as one of your school science teachers.

You will also need some mechanical skills to build this project: using an electric drill and cutting holes in metal. You'll also need to be able to do simple glass working with glass tubing.

You will need an electronics "multimeter" for testing and trouble-shooting the controller circuit, and knowing how to make basic resistance, voltage and continuity checks. You must be familiar with safety requirements for working with AC powered circuits before building or testing this project!

If you'd like to get started in building electronics devices, one of the best ways is building an electronic device from a kit. Such kits are available from Radio Shack stores and other electronics hobbyist sources. Radio Shack also has several books, including *Getting Started in Electronics*, which will help you learn the basics of electronics theory and construction techniques.

Supplies and Parts Sources

Chemicals and glassware:

Laabs, Inc., 911 N. 27th Street, Milwaukee, Wisconsin 53205

Hagenow Laboratories, Inc. 1302 Washington Street, Manitowoc, Wisconsin 54220

Electronic parts:

Digikey Corp., 701 Brooks Avenue South, P.O. Box 677, Thief River Falls, Minnesota 56701-0677

Hankscraft, 728 Booster Blvd., Box 120, Reedsburg, Wisconsin 53959

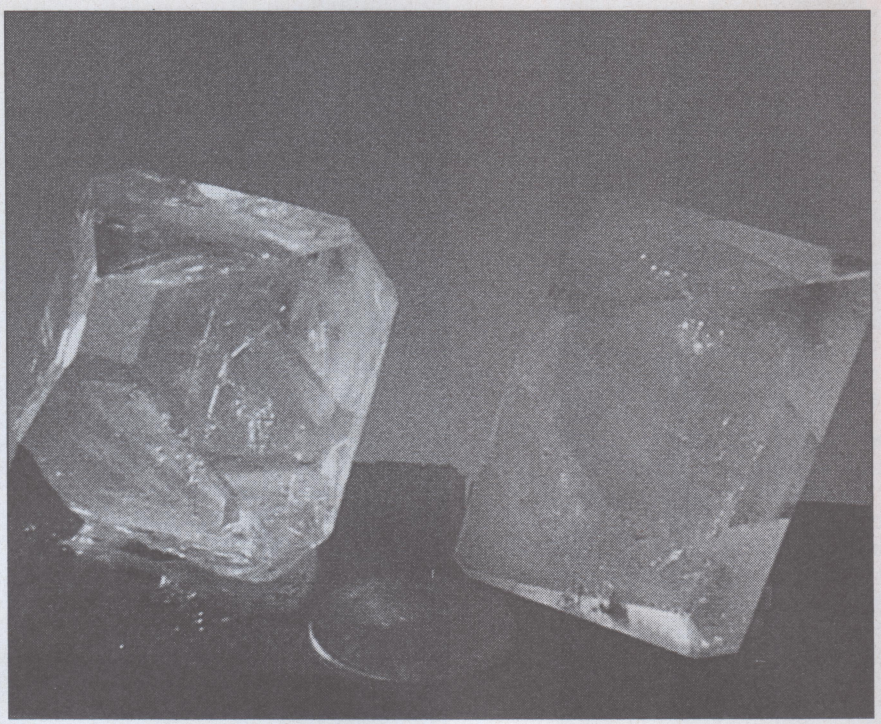
Allied Electronics (a good source for an isolation transformer and/or ground fault breaker). Call (800) 433-5700 and ask for a catalog.

Radio Shack

FURTHER READING

Crystals and Crystal Growing by Allan Holden and Phyllis Singer. (MIT Press, Cambridge, Massachusetts, 1960).

Journal of Chemical Education. Many of the back issues (to the early 1900s) include articles worthy of your time.



Potassium dichromate crystals are easy to grow.

PARTS LIST

Controller Assembly

C1 — 100 uF 35V electrolytic capacitor (Radio Shack 272-101)
C2 — 4.7 uF 35V electrolytic capacitor (Radio Shack 272-1024)
F1 — 2 Amp 3AG fuse (Radio Shack 270-1274)
Q1 — TRIAC, 4-10 Amp, 400V isolated-mount (Teccor Q4008L4 or equivalent, Digikey)
R1 — 220K ¼ watt resistor
R2 — 15K ¼w resistor
R3, R4, R5 — 10K ¼w resistor
R6, R11 — 470 ohm ¼w resistor
R7 — 1K potentiometer (Digikey 53C1 102-ND)
R8 — 5K potentiometer (Radio Shack 271-1714)
R9 — 4.7K ¼w resistor
R10 — 2K ½w resistor
R12 — 270 ohm ½w resistor
R13 — 33K ¼w resistor
S1 — SPST toggle switch, ¼" bushing (Radio Shack 275-612)
T1 — 24-25V 450 mA transformer (Radio Shack 273-1366)
Th1 — 10K @ 25°C thermistor (Radio Shack 271-110)
U1 — 555 timer IC (Radio Shack 276-1723)
U2 — LM358 dual op amp IC (Digikey)
U3 — Harris CA3059 zero-crossing switch IC (Digikey)
U4 — Motorola MOC3010 triac optocoupler (Radio Shack 276-134)

Miscellaneous:

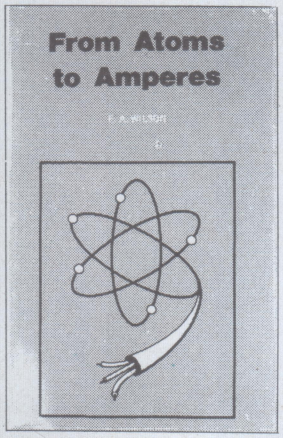
Box, electrical, plastic, 4" square
Circuit board, perforated (Radio Shack 276-168)
Clamp for power cord (1)
Fuse holder (Radio Shack 270-364)
Knob, for ¼" (6.35 mm) shafts (2)
Label kit, rub-on (Radio Shack 270-201)
Miscellaneous hardware
Power cord, 3-wire w/plug (Radio Shack 278-1258)
Socket for 14-pin DIP IC (1)
Socket for 8-pin DIP IC (3) (can use two sets of Radio Shack 276-1975 SIP sockets cut to length)

Pyrex Container and Heating Element Assembly

AA alkaline cell (2)
Battery holder, for AA cells (Radio Shack 270-382)
Flood lamp bulb, 150 watt, outdoor-type
Glass tubing, approx. 6-8 mm OD, 30 cm (12") long
Grommet, ½" (for power cord)
Hardware cloth, ¼" mesh (See text.)
Miscellaneous screws, hardware, scraps of wood for lamp support
Motor, agitator (Hankscraft 30 RPM, 4.5 VDC type preferred)
O-ring, 6 mm (¼") (5)
Printed circuit board material, epoxy-glass, approx. 18 cm (7") square
Pyrex container (See text.)
Socket, surface-mounting, for 150 watt lamp
Stainless steel rods or styrene tubing for agitator (See Figure 9.)
Thermometer, 100°C, glass
Window screening, metal (same size as hardware cloth)
Wire, hookup, #22 or #24 gauge (as required)
Wood base, ¾" thick, 10" square (2 cm x 25 cm square)

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☐ FROM ATOMS TO AMPERES—BP254— $6.50

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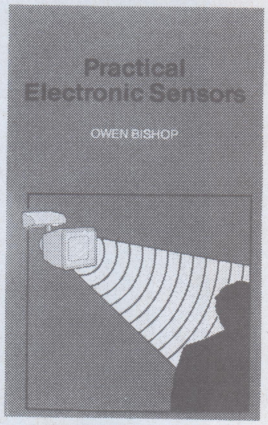
Wondered about the true link between electricity and magnetism?

Felt you could never understand the work of Einstein, Newton, Boltzmann, Planck and other early scientists?

Just accepted that an electron is like a little black ball?

Thought the idea of holes in semiconductors is a bit much?

Then you need this book. It explains as simply as possible the absolute fundamentals behind electricity and electronics.

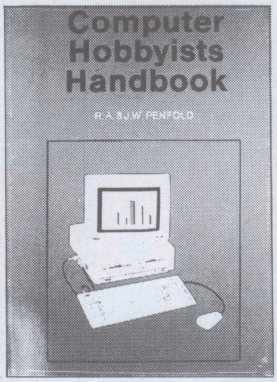


☐ PRACTICAL ELECTRONIC SENSORS—BP273—$6.95

From satellite surveillance and industrial process control to the more mundane matter of detecting when the toast is the right shade of brown, there are very few electronic circuits which do not involve a sensor of some kind. The book contains a dozen construction projects for in and around the home.

☐ COMPUTER HOBBYISTS HANDBOOK—BP251—$8.95

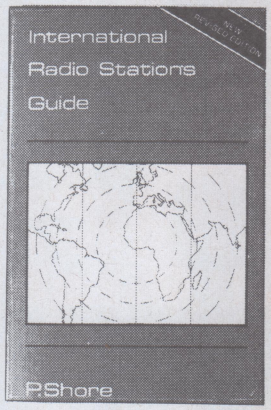
Subjects covered include microprocessors and their register sets; interfacing serial, paralley, monitor, games and MIDI ports; numbering systems, operating systems and computer graphics. While the book is aimed at the computer hobbyist, it should also prove useful to anyone who intends to use a computer to follow their interests.

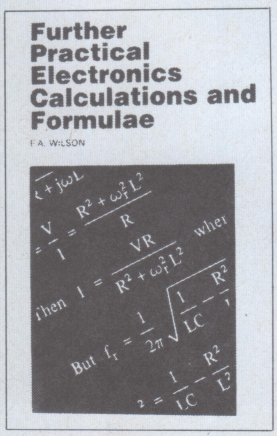


☐ INTERNATIONAL RADIO STATIONS GUIDE—BP255—$9.95

Provides the casual listener, amateur radio DXer and the professional radio monitor with an essential reference work designed as a guide for the complex radio bands.

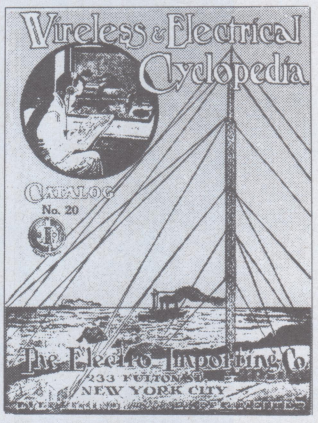
Includes coverage on Listening to Short Wave Radio, ITU Country Codes, Worldwide Radio Stations, European Long Wave and Medium Wave Stations, Broadcasts in English and more.





☐ FURTHER PRACTICAL ELECTRONICS CALCULATIONS—BP144—$9.00

450 pages crammed full of all the formulae you are likely to need. Covers Electricity, Electrostatics, Electromagnetism, Complex Numbers, Amplifiers, Signal Generation and Processing, Communications, Statistics, Reliability, Audio, Radio Systems, Transmission Lines, Digital Logic, Power Supplies. Then there's an appendix of Conversion Factors, Mathematical Formulae and more.



☐ WIRELESS & ELECTRICAL CYCLOPEDIA—ETT1—$5.75

A slice of history. This early electronics catalog was issued in 1918. It consists of 176 pages that document the early history of electricity, radio and electronics. It was the "bible" of the electrical experimenter of the period. Take a look at history and see how far we have come. And by the way, don't try to order any of the merchandise shown, it's unlikely that it will be available. And if it is, the prices will be many times higher.

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Summary

Five hundred years ago the inhabitants of what is now Mexico had no idea that a trio of ships had made the crossing from Europe to the Caribbean. Although their advanced civilization would soon be demolished, many of the imposing structures they had erected would survive to the present. Janet and William Barden have visited some of the pre-Columbian sites of Mexico and here is their report.

Story and Photographs by Janet K. Barden and William Barden Jr.

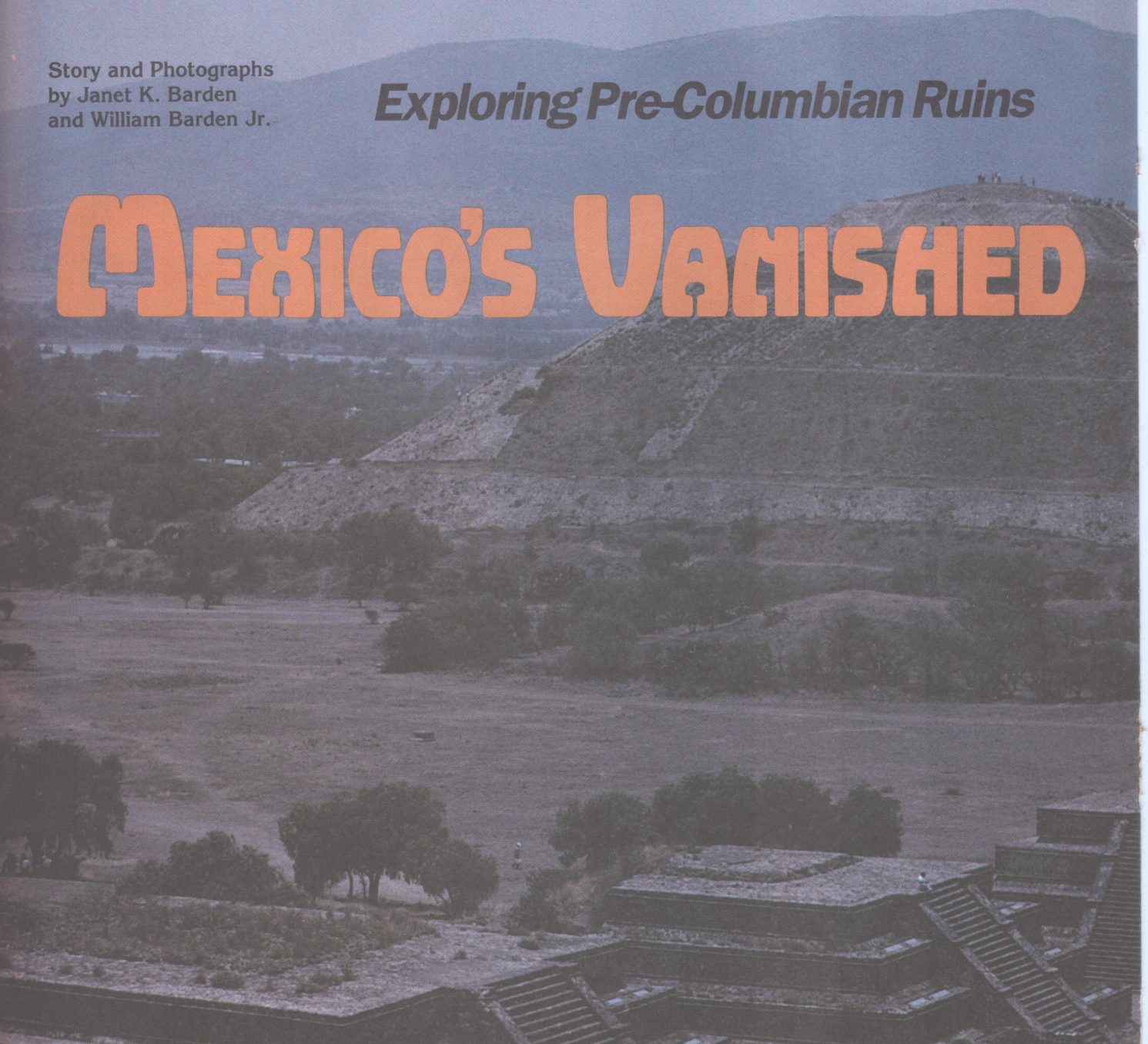
Exploring Pre-Columbian Ruins

Mexico's Vanished

Conquistadors sought gold and other precious minerals in the New World and found them. But, Mexico has more than precious minerals — it has a rich historic past, a wealth of anthropological reminders of vanished, or nearly vanished, civilizations — Toltec, Aztec, Olmec, Maya and others.

The ancient Mexican cultures can be related on several levels to the fascinating culture of ancient Egypt — they were the dynamic, innovative cultures of the New World. For example, Maya inventions like the corbeled arch, mathematical zero, astronomical building alignments, and the sheer size and splendid architecture of some of the structures denote a sophisticated culture in its own right.

Janet had studied these civilizations in detail, and together we had visited several sites on previous trips. This time, though, we wanted a more comprehensive tour, a micro "grand tour" of sites — as many as we could cram into less than two weeks. The result of Janet's planning was a trip in which we covered more than 6,900 kilometers (4,300 miles), explored a dozen different sites, and took more than 1,000



slides. It was an exhilarating experience! You may not wish to repeat the somewhat hectic pace of our complete trip, but any portion of it is an incredible adventure. Some of the highlights are mentioned here.

Mexico City and the National Museum of Anthropology

The first leg of the trip was from Los Angeles to Mexico City via Mexicana Airlines. Mexico City is a reasonable starting point for such a tour because it is the gateway to the most significant archaeological sites in Mexico and Central America.

(Numerous sites exist north of Mexico City, but they are somewhat less important in size and relationship to the Maya culture, the main focus of our trip.)

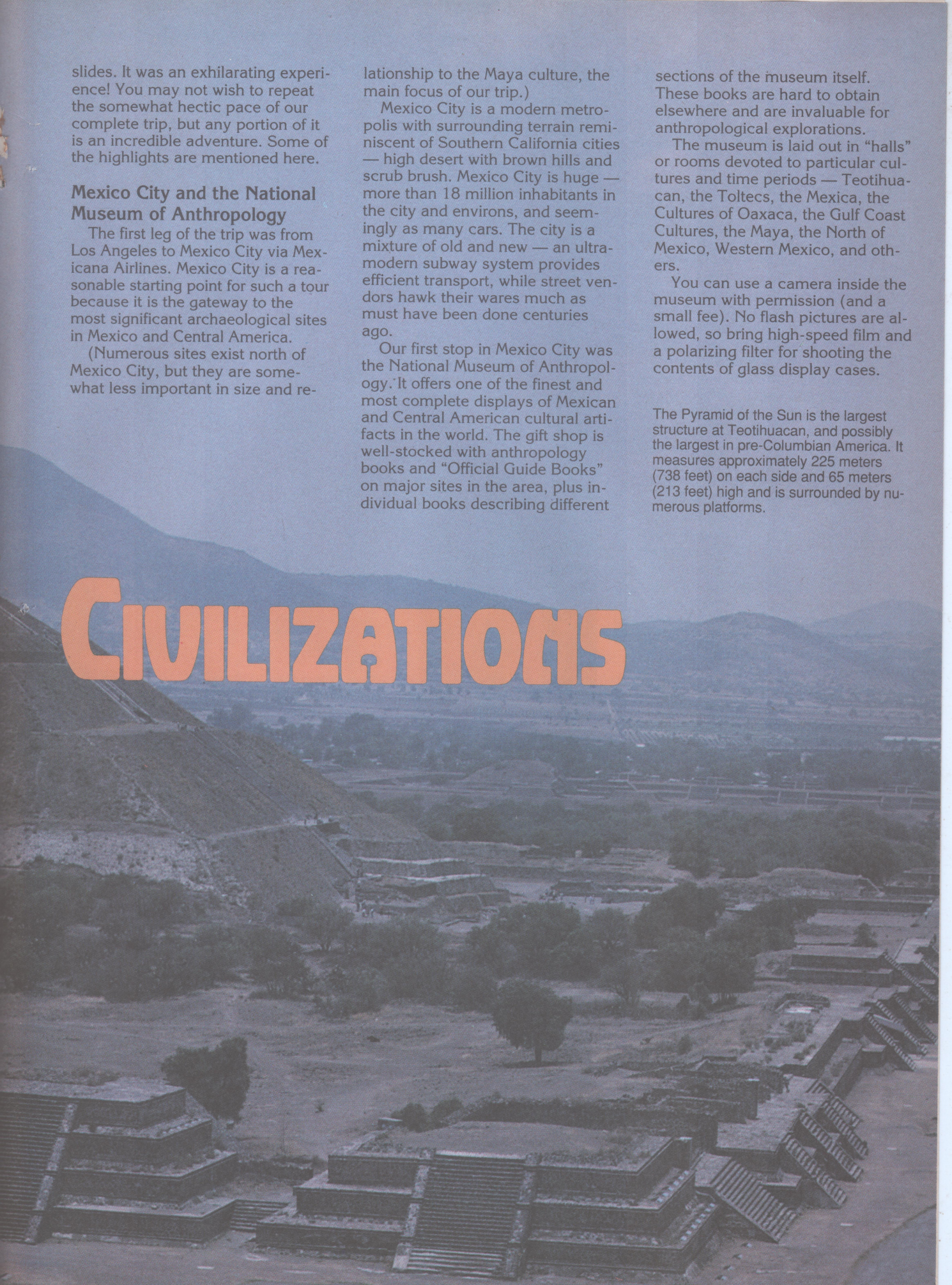
Mexico City is a modern metropolis with surrounding terrain reminiscent of Southern California cities — high desert with brown hills and scrub brush. Mexico City is huge — more than 18 million inhabitants in the city and environs, and seemingly as many cars. The city is a mixture of old and new — an ultra-modern subway system provides efficient transport, while street vendors hawk their wares much as must have been done centuries ago.

Our first stop in Mexico City was the National Museum of Anthropology. It offers one of the finest and most complete displays of Mexican and Central American cultural artifacts in the world. The gift shop is well-stocked with anthropology books and "Official Guide Books" on major sites in the area, plus individual books describing different sections of the museum itself. These books are hard to obtain elsewhere and are invaluable for anthropological explorations.

The museum is laid out in "halls" or rooms devoted to particular cultures and time periods — Teotihuacan, the Toltecs, the Mexica, the Cultures of Oaxaca, the Gulf Coast Cultures, the Maya, the North of Mexico, Western Mexico, and others.

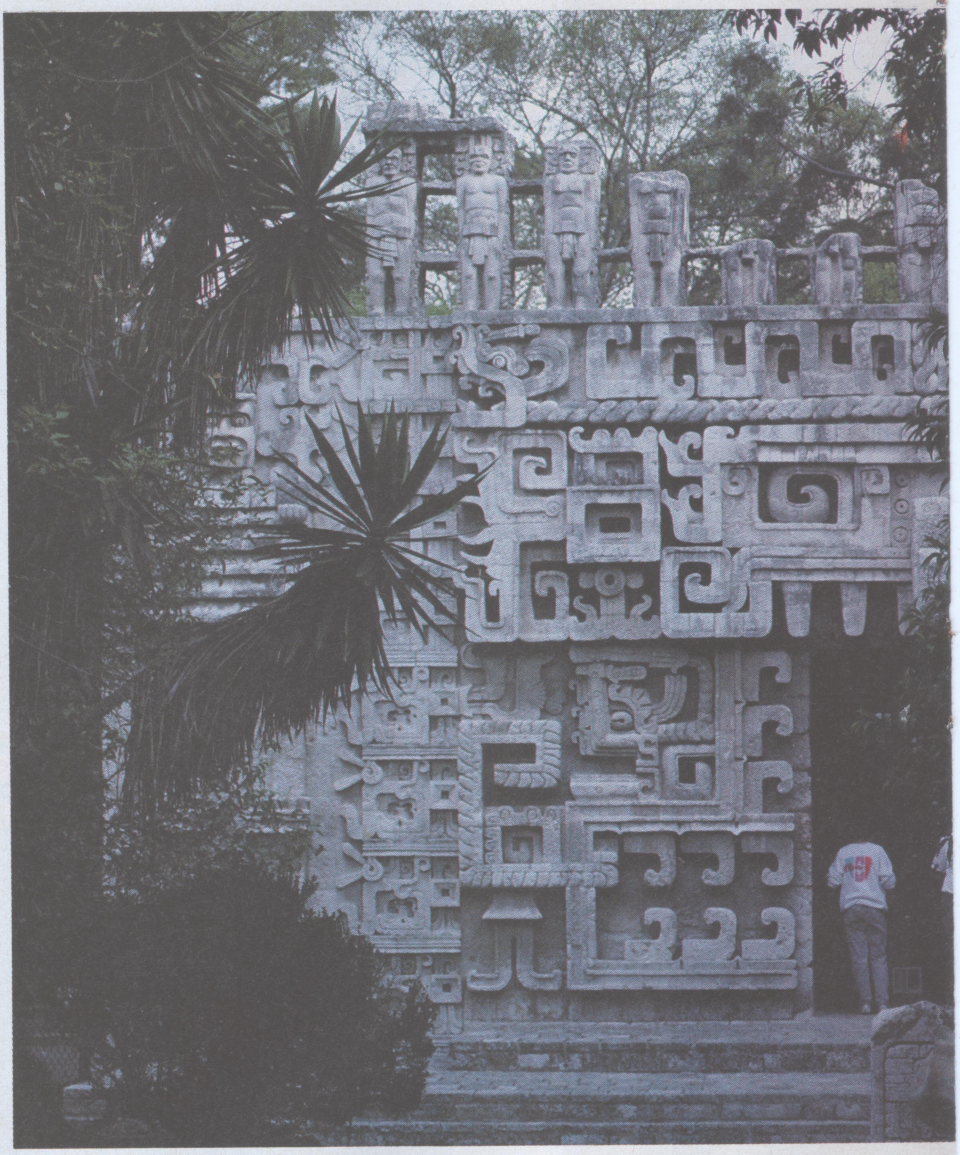
You can use a camera inside the museum with permission (and a small fee). No flash pictures are allowed, so bring high-speed film and a polarizing filter for shooting the contents of glass display cases.

The Pyramid of the Sun is the largest structure at Teotihuacan, and possibly the largest in pre-Columbian America. It measures approximately 225 meters (738 feet) on each side and 65 meters (213 feet) high and is surrounded by numerous platforms.



Mexico's Vanished Civilizations

Temple II of Hochob from the State of Campeche. The facade in the front represents an enormous mask with the mouth used as an entrance, an example of "chenes" style architecture. (National Museum of Anthropology, Mexico City)



Teotihuacan

The next stop after the museum was the huge, well-restored archaeological site of Teotihuacan, about 48 km (30 miles) northeast of Mexico City. Although you may arrange for tours from larger Mexico City hotels, we found it more adventurous, more efficient, and much less expensive, to take the subway (Metro) to Terminal de Autobuses Norte, a bus hub, from which you can catch a regional bus to Teotihuacan.

Teotihuacan was first occupied by tribal groups around 100 B.C., but soon grew to a large metropolis with a population reaching at least 60,000 in the fourth phase around A.D. 600. Although little is known about the different groups that invaded and occupied Teotihuacan over the centuries, we do know that the Aztecs later considered it a setting for cosmic myth, and their last ruler, Motecuhzoma II, made pilgrimages to the site.

One of the most significant aspects of the site of Teotihuacan is its geometric layout in a grid form with two great perpendicular axes running approximately north to south and east to west. Within this framework were constructed great temples, plazas and ritual walkways, but the largest and most impressive structures at the site are the Pyramid of the Sun and the Pyramid of the Moon.



This facade of a temple at Teotihuacan is decorated with a representation of the plumed serpent, Quetzalcoatl, an important figure in Mexican and Maya mythology.

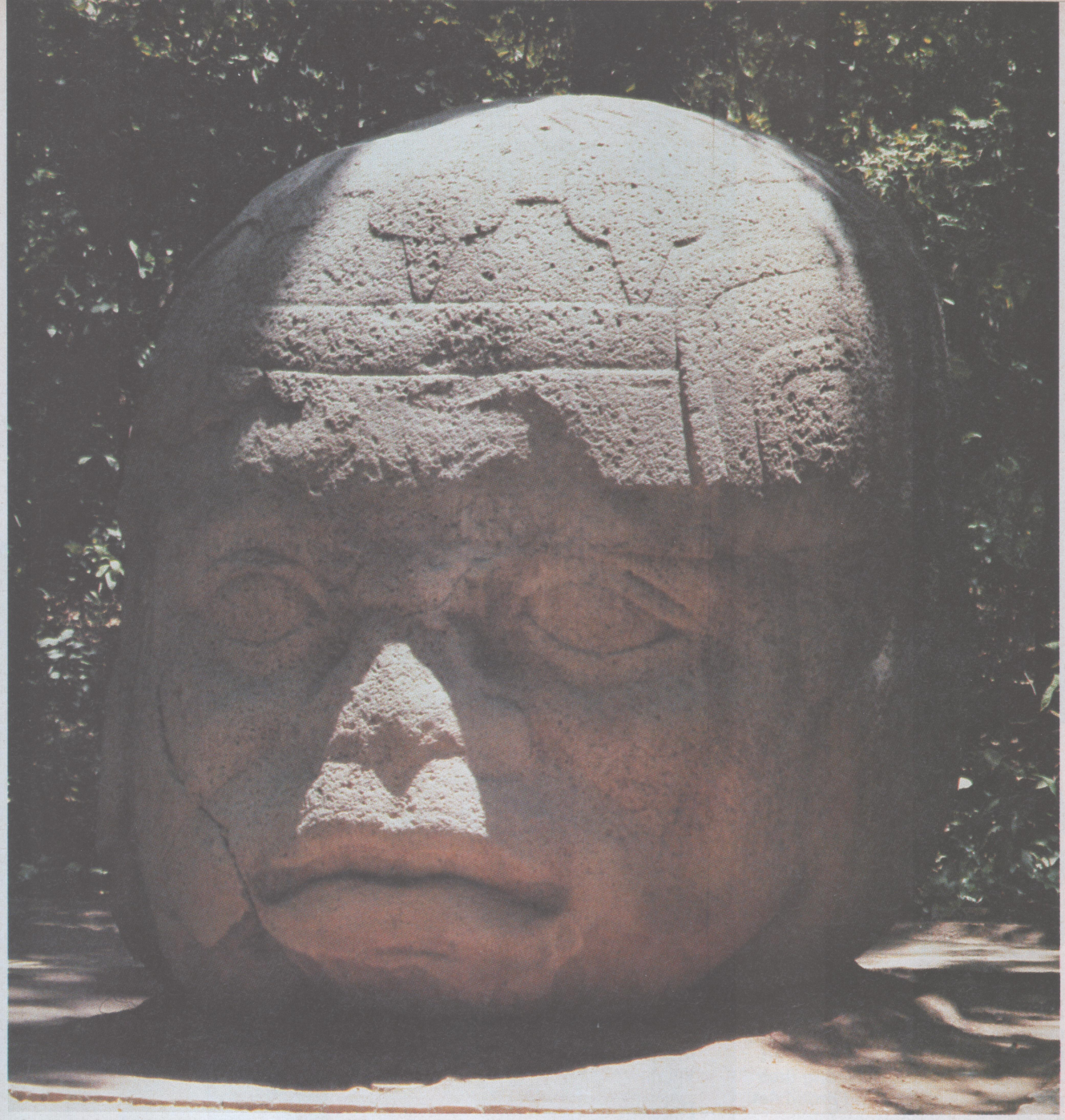
These monumental structures have been studied by archaeologists and astronomy experts for many years in an attempt to find out their relationship to archaeoastronomy. One theory is that the pyramids were built for the two gods who became the sun and the moon in ancient Mexican mythology.

The principal axis of Teotihuacan is known as the "Street of the Dead." It is flanked on both sides by plazas and platforms, with the Pyramid of the Moon located at one end. The Street of the Dead is actually situated 15 degrees 28 minutes east of north, and petroglyph markers found in the vicinity have led scholars to theorize that the Pleiades may have been the astronomical source for Teotihuacan's curious orientation at the time of its construction around A.D. 150.

Tenochtitlan

Traveling to Teotihuacan was relatively easy, but there was another site even more accessible. In 1978, employees of an electric light company working in the heart of Mexico City unearthed part of a large monolith, which represented the Moon deity, Coyolxauhqui, in Mexica (Aztec) mythology.

This discovery created a renewed interest in the site known as Tenochtitlan, and eventually led to the excavation and investigation of



Colossal Olmec head, one of many artifacts relocated to La Venta Park Museum after the discovery of oil on the Gulf Coast.

the Great Temple of Tenochtitlan, which had been described by chroniclers centuries earlier.

The city of Tenochtitlan was founded by the Mexicas about A.D. 1325 and remained the hub from which they controlled 370 nations until the Spanish arrived in the early 1500s.

Of particular interest at Tenochtitlan are the causeways that linked it with the surrounding dry land. One of these causeways, Iztapalapa, was used by the Spanish in 1520 to gain access to Tenochtitlan; and another, Tlacopan, was used when they attempted to flee on the night known as "Noche Triste" (sorrowful night) and suffered defeat from the Mexicas.

Although Tenochtitlan is not one of the most impressive sites, it's interesting to see the contrast of this ancient city to its modern Mexico City surroundings. The symbols that you see while walking through the ruins are a curious mixture of Mexica and Toltec mythology. For instance, the "Tzompantli Altar" or shrine located north of the Great Temple is similar to the "skull rack" found at the Toltec-influenced site of Chichen Itza.

Villahermosa, La Venta Park and CICOM

Leaving Mexico City by Mexicana, we flew 645 km (400 miles) east to our next stop. Villahermosa ("beautiful town") with a population of more than 250,000, is a relatively new city with many modern buildings, and parts of it **are** beautiful. Much of its growth can be attributed to the proliferation of Pemex oil wells along the Gulf coast near Villahermosa.

Oil development caused a boom and forced the relocation of an entire Olmec ceremonial center from the marshy coast to La Venta Park (Parque-Museo La Venta) in Villahermosa.

La Venta Park now contains many colossal heads and other artifacts, which are the trademark of Olmec culture.



The Palace at Palenque is about the size of a U.S. city block. It was constructed and remodeled during a 120-year period of Maya history.

Mexico's Vanished Civilizations

Unfortunately, little is known about the people who built the Olmec civilization. Clues to the Olmecs exist primarily in their art — statues of heads depicting their rulers with thick lips and broad flat noses. Another common Olmec statue depicts the were-jaguar figure, a cross between a jaguar and a human that is often represented as a baby.

We do know that the Olmecs predated the Maya and other Mexican cultures like Teotihuacan by about 1,000 years. They flourished in an area about 200 km (125 miles) along the Gulf coast of Mexico between the period of 700 and 500 B.C. Whether or not they were actually the ancestors of any later Mexican culture is still under discussion — the consensus of opinion says probably not.

Villahermosa also has an excellent archaeological museum that is located in the CICOM (Centro de Investigaciones de las Culturas Olmeca y Maya) complex along the Grijalva River. CICOM itself is a complete investigation center for Maya and Olmec cultures.

We focused on the Museo Regional de Anthropologia Carlos Pellicer Camara. The museum is one of the better museums for Mexican artifacts, containing four floors of wonderful relics from the Olmec, Maya and Toltec cultures. It's a must see if you are visiting Villahermosa.

Palenque

We rented a car and drove to the Palenque site, an easy 145 km-drive (90 miles) on good roads. The morning was somewhat misty, adding an almost supernatural appearance to our first glimpse of the jungle site. Many of the buildings are yet unexcavated, but you can still get an excellent idea of what the city must have been like during its peak around A.D. 600 to 800. The most impressive structures are in the main temple group, which consists of the Palace, Temple of the Inscriptions, Temple XIII, Temple XIV, and the three temples of Lord Chan-Bahlum: Temple of the Cross, Temple of the Foliated Cross and the Temple of the Sun.

One of the most unique features

of Palenque is the tomb of Lord Shield Pacal (A.D. 615 to 683), located beneath the Temple of the Inscriptions. This tomb was discovered around 1950 by the famous Mexican archaeologist Alberto Ruz. It represents one of the most remarkable discoveries in the Maya area, as most other graves of Maya rulers have been plundered by robbers. This discovery provided a wealth of archaeological information on the life and death of Lord Pacal and his family.

Of particular importance is the lid to his sarcophagus, which depicted Lord Pacal at the moment of death falling into the jaws of the underworld. According to one interpretation, the lid was conceived as a power object to instruct Pacal's soul

Recommended Books on Travel and Archaeology in Mexico

A Forest of Kings — The Untold Story of the Ancient Maya by Linda Schele and David Freidel (William Morrow & Co., New York).

Guide to the Yucatan Peninsula including Belize by Chicki Mallan (Moon Publications, Chico, California).

Baedecker's Mexico (Prentice-Hall, Inc., Englewood Cliffs, New Jersey).

The Best Mexican Travel Tips by John Whitman (Harper & Row, New York).

Birnbaum's Mexico 199-(year) by Stephen Birnbaum, editor (Houghton Mifflin Company, Boston, Massachusetts).

Kingdoms of Gold, Kingdoms of Jade by Brain M. Fagan (Thames and Hudson, New York).

22 Days In Mexico, The Itinerary Planner by Steve Rogers and Tina Rosa (John Muir Publications, Sante Fe, New Mexico).

The Temple of the Inscriptions at Palenque where the tomb of Lord Pacal, a famous Maya ruler, is located.



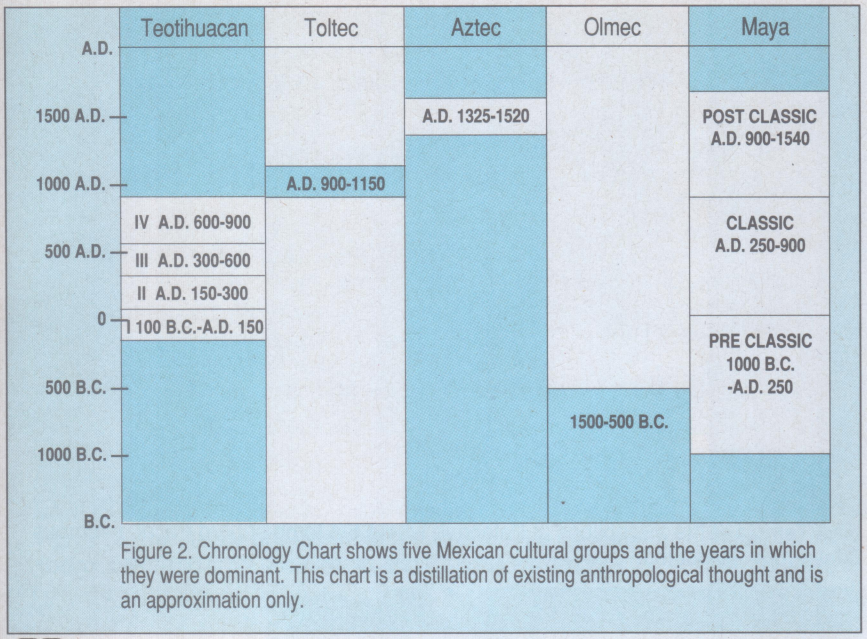


Figure 2. Chronology Chart shows five Mexican cultural groups and the years in which they were dominant. This chart is a distillation of existing anthropological thought and is an approximation only.

Merida

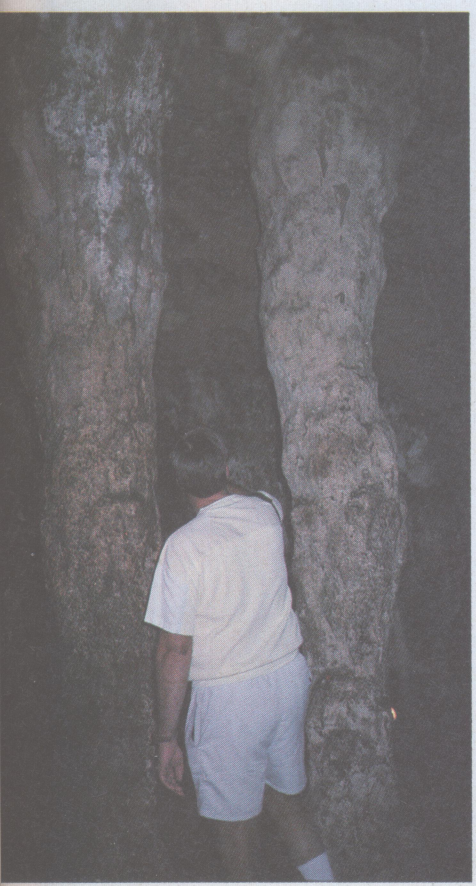
Back at Villahermosa, we boarded an Aero Caribe flight to Merida, about 480 km (300 miles) northeast of Villahermosa.

Merida, with a population of more than 600,000, is the largest city on the Yucatan Peninsula. Founded by the Maya, it became one of their large commercial centers. When the Spanish arrived in the mid-1500s, it reminded them so much of Merida in Spain that they renamed the city. Merida became the seat of civil and religious authority under Spanish rule.

The indigenous Maya were forced into servitude and slavery by the Spanish who made them tear down their palaces and temples to build colonial buildings instead. In the late 1840s the Maya finally rebelled in what is known as the

Mexico's Vanished Civilizations

Bill Barden tests the sound from two stone pillars. They were reportedly used by ancient Maya to imitate the sound of drums at Loltun caves.



during its journey through the underworld and to represent Pacal's final destination among his ancestors. The sides of the sarcophagus depict seven of Pacal's ancestors emerging from a cleft in the Earth, and the edges of the lid contain the dates of Pacal's birth and death.

All of this can be seen if you feel adventurous and wish to climb a very steep and slippery stairway down into the depths of the pyramid. We had been warned about the unreliable lighting and would have had to suffer through 10 minutes of absolute blackness had it not been for Janet's pocket flashlight.

For claustrophobic travelers, there's a wealth of other interesting things to see. The Palace courtyard contains a tablet of life-sized figures representing captives or possibly subservient chiefs. This tablet is an excellent representation of the characteristics often seen in Maya art with the side profile views, prominent noses, head gear and other ornamentation. A small museum contains a few of the less significant artifacts from Lord Pacal's tomb. Unfortunately, Pacal's jade mask and other valuable items from his tomb were stolen from a museum in Mexico not too long ago.

Another interesting element of Palenque are the Lacandon Maya Indians you are apt to see at the entrance to the complex.

The Lacandons are dressed in their white robes and selling their wares in much the same way their ancestors did centuries ago. They are some of the few remaining Maya who cling to traditional ways.



"Caste War," one of the bloodiest battles in Mexican history.

Merida is an ideal base of operations for an anthropologist, because there are dozens of interesting sites within an 129 km (80 miles) radius of the city. Although we could have rented a car, we opted for local knowledge, thinking it would be more efficient in our limited schedule. As it turned out, this was an excellent idea, as many of the sites are off the main roads and hard to find.

The Loop From Merida — Loltun Caves, Labna, Sayil, Kabah, Uxmal, Merida

Our main goal on this leg of the trip was to travel from Merida to Loltun Caves, and then visit the sites of Labna, Sayil, Kabah and Uxmal, all in relatively close proximity. It was a difficult day's trip, but well worth the effort.

We first visited Loltun Caves, the largest known underground caverns in Yucatan. They were used by the Maya numerous times throughout history both for ceremonial purposes and as a refuge from the Spanish. Inside the caves, there are natural rock formations, less exotic than Carlsbad Caverns, but you can see the fascinating remnants of more than 2,000 years of Maya occupation in the form of rock carvings and hieroglyphic inscriptions.

A note of caution about this site: do not attempt to enter the extensive caves without a guide (and flashlight). The caves were made exciting for us by the guide's comment when the lights went out, that we could "find our way back." As we were one-half mile in, over a twisting rocky path sprinkled with stalactites and stalagmites, this would have been quite a chore.

Labna, Sayil and Kabah are all considered minor sites, but are still important because of their relationship with the major site of Uxmal, which we also visited. All of these sites were built in the Late Classic Period (about A.D. 700-900) when Puuc-style architecture was being used. Puuc-style is considerably different than the architectural style of most other Maya sites except for Old Chichen Itza.

The Labna corbeled arch shown here is an excellent example of Puuc-style Maya architecture. It displays a beautiful thatched Maya hut carved in stone on either side of the archway.



Mexico's Vanished Civilizations

What makes Puuc architecture so unique? It's the use of Greek-style columns and intricate mosaic facades which depict characters of importance in Maya mythology like Chac (the long-nosed Rain God) or the Sky Serpent. Puuc architects also constructed large palace platforms with multi-storied layers, such as the Palace at Sayil. Probably, the most important feature of these sites, however, is the use of the "sacbe," or ceremonial way, which is thought to have spiritually (as well as literally) connected these sites to nearby Uxmal.

"Uxmal" is the Maya word for "thrice built," but it is actually believed to have been rebuilt five times. Constructed on a grand scale, it obviously served as a major urban center for the Maya during the Late Classic Period. The population is estimated to have been more than 20,000 before it was abandoned around A.D. 900.

Much of Uxmal has now been excavated, and unique buildings such as the Pyramid of the Magicians, Nunnery Quadrangle, Palace of the Governor, and others can be seen in a few hours of sightseeing. In this case, the buildings are a blend of both Puuc and Chenes styles with some Mexican-influenced art.

Like those we saw in Teotihuacan, the major buildings at Uxmal appear to have been built with astronomical alignments in mind, being located on a single north-south axis. However, the Palace of the Governor is noticeably skewed to face the southernmost rising point for Venus at the time that Uxmal was built. Further confirmation of a preoccupation with Venus is seen in more than 350 emblems of the planet carved into the upper facade of this building.

From Merida to Chichen-Itza

Leaving Merida we departed for Cancun by van — about a five-hour trip. The route passes the most popular Maya site, Chichen Itza.

Archaeological evidence suggests that Chichen-Itza was settled by the Maya prior to A.D. 200, became a minor urban center by A.D. 600-800, and then allied with coastal and highland Mexican groups. It was taken over by the Toltecs around A.D. 1000. They developed it into a major urban center and the seat of central authority for the entire peninsula. Chichen Itza eventually fell, and another site, Mayapan, became the major political and economic center for the area.

However, the Sacred Cenote (sink hole) at Chichen Itza had become an important shrine under Toltec rule. It continued to function as a major ceremonial center and place of pilgrimage until well into the 16th century. In fact, the cenote has gained the reputation of being a "Cenote of Sacrifice" because of the hundreds of sacrificial victims found in it, along with other ritual objects from that time period.

One of the most imposing buildings at Chichen Itza is El Castillo, a giant pyramid. Until a few years ago, the interior of the pyramid could be accessed via a narrow stairway that led to a platform containing a Red Jaguar Throne with in-



laid jade. The last time we visited the site you could no longer access this room, but the exterior of the pyramid is still of great interest. It attracts thousands of visitors during the spring and fall equinoxes, because the light of the setting sun during that time creates an image of writhing serpents along the balustrade on the north face of the Castillo.

Equally interesting is the great Ballcourt at Chichen Itza. It is one of the best preserved ballcourts in the New World and contains a ritual scene carved out of stone. The carving depicts the Maya ballgame, a game reminiscent of soccer. Much has been written about the interpretation of this scene. Some scholars say it may re-enact the legend of the mythical Hero Twins' exploits in the underworld as they attempt to win the game and spare their own lives, unlike their less fortunate father. We do know that it depicts a beheading, which gives us a clue as to the fate of the loser of the game.

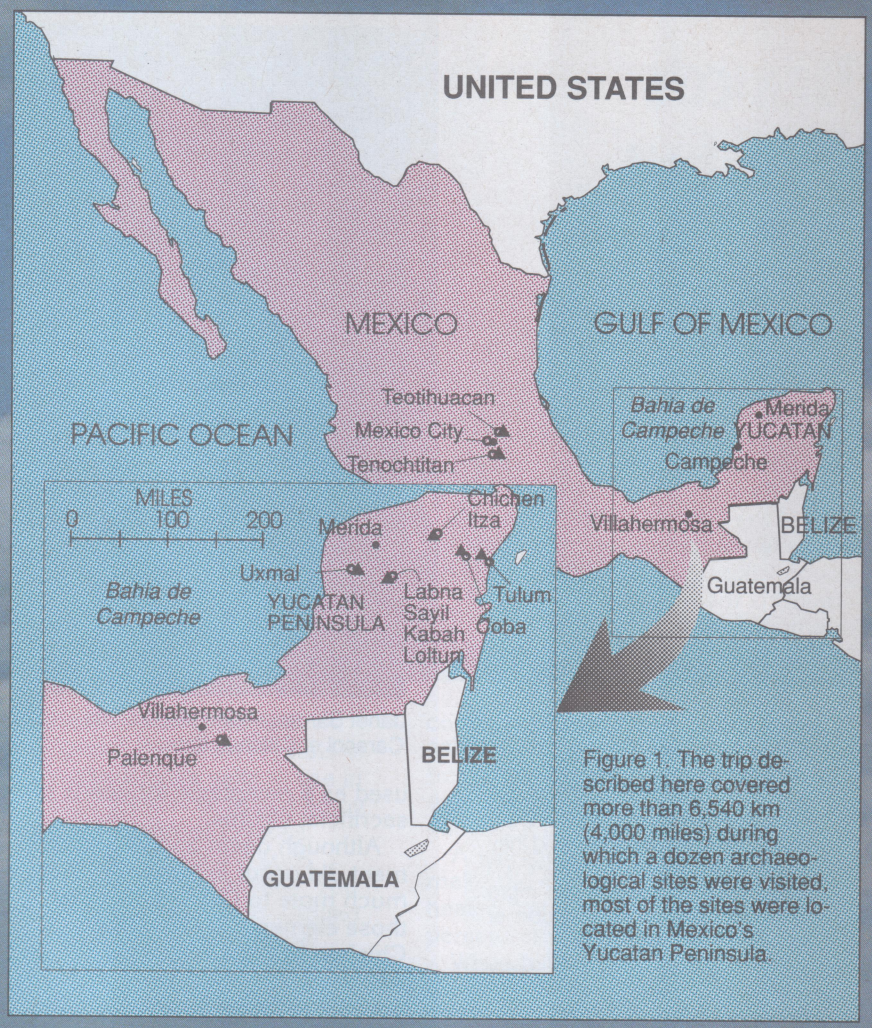
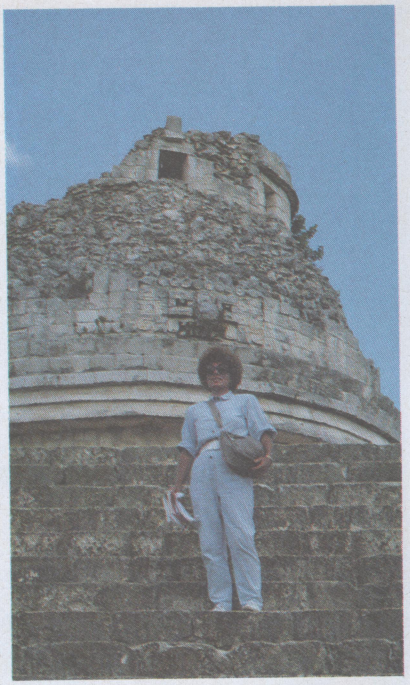


Figure 1. The trip described here covered more than 6,540 km (4,000 miles) during which a dozen archaeological sites were visited, most of the sites were located in Mexico's Yucatan Peninsula.

The Caracol at Chichen Itza with El Castillo in the background. This circular structure was probably used as an astronomical observatory by the Maya.

Mexico's Vanished Civilizations

Toltec influence at Chichen Itza can best be seen in the Temple of the Warriors complex. It is flanked on two sides by the Temple of a Thousand Columns and bears an amazing similarity to the Temple of the Atlanteans at Tula, a Toltec site north of Mexico City. Located at the portal of the Temple of the Warriors, between two carved stone images of Kukulcan (the Feathered Serpent) is the reclining figure of Chacmool, also of Mexican origin. The flat surface on the stomach of Chacmool is thought to have been used as a receptacle for hearts of sacrificial victims.



Janet Barden on the steps of the Caracol at Chichen Itza.

Although death and dismemberment did occur in Maya life, there's much more to Chichen Itza than those elements of the culture. Chichen Itza is a wonderful site and well worth the effort to go there, especially because it can easily be visited in a half-day tour originating from Cancun.

Cancun

We continued on to Cancun. Cancun is completely and unabashedly modern, having been built specifically for the tourist trade from swampland. It is reminiscent of Palm Beach. If you're not into glitzy beach cities, however, there are many archaeological sites near Cancun. And it's a good base of operations. The roads through Yucatan are excellent two-lane roads (but with no shoulder). Less than 100 years ago jaguars abounded in the surrounding jungle, but, like Maya traditional huts, they are now a vanishing species here.

Coba

From our base in Cancun, we rented a garish VW and started the drive to Coba, about 180 km (110 miles) south and west over excellent roads. Water in the gas made the trip more exciting.

Most of the ruins of Coba are still unexcavated and lie beneath dense jungle growth, making it a more primitive site to visit than the others we've mentioned so far. It was first discovered in the late 1800s, but no major archaeological effort was made there until the 1970s. It has been estimated that more than 6,500 structures are at this site, which may prove to be of considerable importance in the puzzle of Mesoamerican history.

Some archaeologists believe that Coba was built and inhabited around A.D. 600-900 by people from the Peten region in Guatemala. The construction of Coba resembles Tikal in that region, rather

Quick Tips for Mexican Travel

The People: Warm and friendly. Don't be an ugly North American, and they will go out of their way for you. Even in major cities the people are more gracious than in Paris, London or Manhattan.

Safety: Theft is prevalent in major cities. Wear a money belt. Guard your belongings, as the Mexicans do. Safer than larger U.S. cities as far as violent crime. Tourists are obvious targets around the world.

Car Travel: Get Mexican insurance. Understand that a traffic accident is serious business. Be sure to read up on *mordida*. Roads are generally good, but get good maps, fill up with gasoline every chance you get, and watch for people and animals in the middle of country roads. Don't drive at night.

Food and Water: From our research, about 50% of tourists have traveler's diarrhea, ranging from mild to severe. Penafiel or other bottled water or soft drinks are fine. Eat at more upscale restaurants.

Hotels: Excellent accommodations in Mexico City, Villahermosa, Merida and Cancun. Clean rooms, good water and food, and gracious help. Smaller towns won't have the quality of hotels some travelers might prefer.

Language: You can get by without Spanish in larger cities or at tourist sites. But, take a phrase book and learn a few dozen phrases related to etiquette, money and emergencies.

Expense: Generally much less expensive than Europe or the United States.

Astronomy and Mesoamerica

Ancient Mexican peoples, as with many ancient cultures, were intimately familiar with astronomy. You will see this reflected in the orientation of ancient pyramids and other buildings as you travel throughout Mexico and the Yucatan. Bring a compass and record the orientations of streets and buildings as you take photographs.

Some examples: The main pyramid at Chichen Itza provides a show to more than 10,000 tourists and locals during the vernal equinox (about March 21). The alignment and construction of the pyramid are such that a giant serpent (an animal of religious significance) appears to undulate in descending fashion down the north balustrade, one hour before sunset. Serpent heads are carved in stone at the bottom of the pyramid, completing the picture.

The ruins at Teotihuacan are defined by the Street of the Dead leading to the Pyramid of the Moon. Rather than a precise north-south alignment, the street is oriented about 15 degrees south of east. The founders of the city were precision builders, and these alignments were no accident. Some authorities believe the east/west axis was determined by the rising and setting of the constellation Pleiades.

The Palace of the Governor at Uxmal is noticeably misaligned from other buildings. Mayan experts have speculated that this building faced the southern-most rising point of Venus at the time the building was constructed.

To investigate the astronomical significance of Mexican ruins, it helps to have a good map, aided by your own notes and observations. Another must is some kind of astronomical reference that will provide the coordinates of celestial bodies at the time of construction. Some excellent tools for this purpose are the astronomy programs discussed in the "Computer Scientist" column of this issue of *Science PROBE!*. Many of the programs can reconstruct the heavens for you on any day in antiquity.

than nearby Puuc sites. The architectural difference can be seen in one of the main pyramids at Coba, the pyramid of the Castillo at Nohoch Mul. This pyramid is 43 meters (142 feet) high and perhaps the tallest in Northern Yucatan.

Home Again

Coba was to have ended our tour, but we did sneak in a brief visit to the minor El Rey archaeological site in the middle of Cancun. After a celebration lobster feast in a comfortable Cancun hotel, we packed our copies of pre-Columbian art, slides, books and brochures for the flight back to another Spanish colonial city — Los Angeles. It had been a fascinating tour, albeit hectic. And, although the sites are not as easy to visit as the Tower of London or the Louvre, they are well worth the trouble.

With much of Mexico's past still hidden in unexcavated sites and many mysteries even in the more restored locations, you can't help but feel like a latter-day explorer, breaking new archaeological ground. Give Mexico and its archaeological past a try. You won't be sorry! ✳

ABOUT THE AUTHORS

Janet Barden holds a bachelor of arts degree in anthropology and is currently completing requirements for a master of arts in anthropology. She is interested in various cultures, including the ancient Maya. William Barden Jr. is the author of many computer books and a regular columnist for *Science PROBE!*.

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Discovering the Ancients Close to Home

Even if a trip to Mexico doesn't fit in your schedule or your budget, you can study early Americans.

By Rita Breedlove

Despite the clear, bright sunshine, the day is bitterly cold. A rugged vehicle bounces along ruts cut into rocky terrain. The Navajo guide hangs out his window pointing high above us to a distant canyon wall.

Stark white figures march across sandstone. We study the drawings, shivering under layers of wool and synthetics, contemplating the messages of the ancient ones who abandoned the craggy beauty of Canyon de Chelly centuries ago.

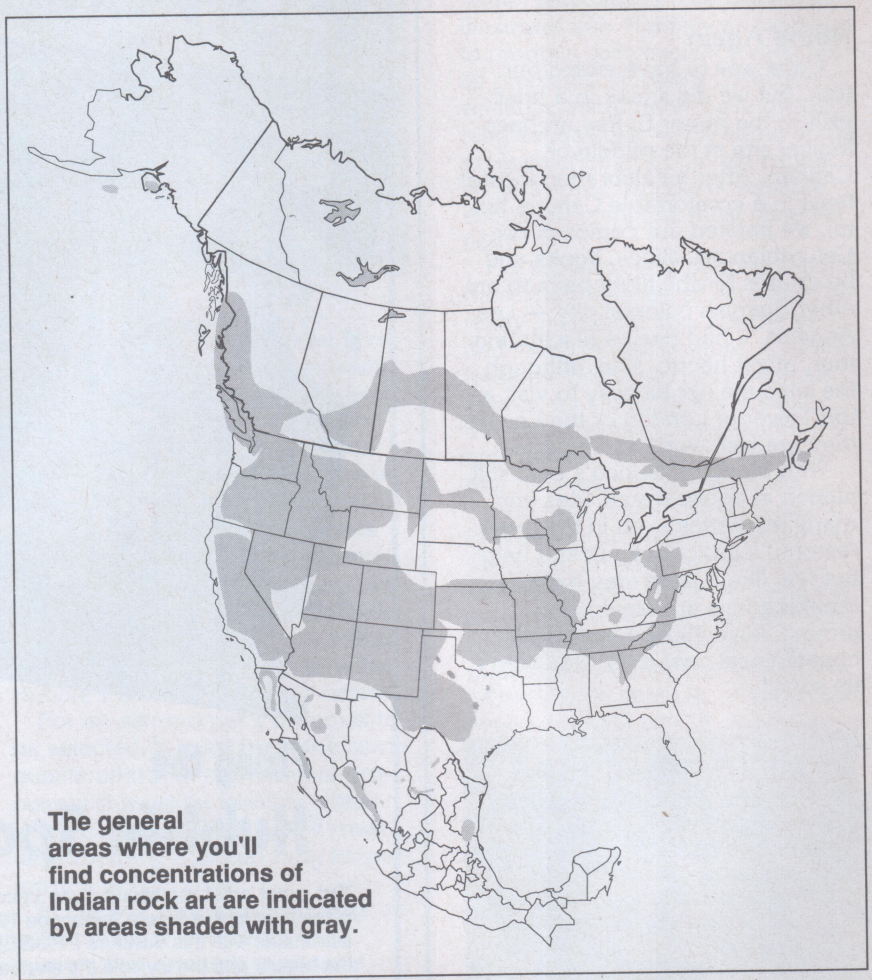
Our driver stops; we explore the ruins of the cliff dwellers as he builds a fire, then prepares hot chocolate to help fight off the January cold. We marvel that primitive peoples walked these paths, endured this cold and left behind their unsolved mysteries.

The mysteries I learned about on a trip through the Four Corners country in the Southwestern United States a few years ago have intrigued explorers, archaeologists, tourists and amateur scientists for more than 400 years. This particular area is one of the largest and most accessible places where Indian rock art has been found.

But across most of the United States and Canada, there are examples of such art. The periods during which these images were created vary widely, dating back to numerous wandering tribes who first settled into relatively permanent homes. Scholars speculate that only when these groups turned to agriculture did they have the time and energy to express themselves in something more than spoken language.

Their artwork is surprisingly similar across the country, and yet differences in individual images draw attention to their artistic style and beauty. Amateur scientists can enjoy them esthetically and study them for the clues they give to ancient cultures.

It's likely that you'll find a rock art site within a day's drive of your



The general areas where you'll find concentrations of Indian rock art are indicated by areas shaded with gray.

Campbel Grant, author of *Rock Art of the American Indian*, identifies four major concentrations of rock art: California, the Columbia Plateau, the Great Basin and the Southwest. Rock art has been found in all but a few of the states in the United States. Grant estimates that there are 15,000 sites in the West and more than 200 east of Mississippi.



Photo by Wylie W. Hawthorn

These pictographs showing shamans with antler headdresses are found in Seminole Canyon in Texas. In *Ancient Texans*, author Harry J. Shafer suggests that these figures are costumed dancers.



Photo by Wylie W. Hawthorn

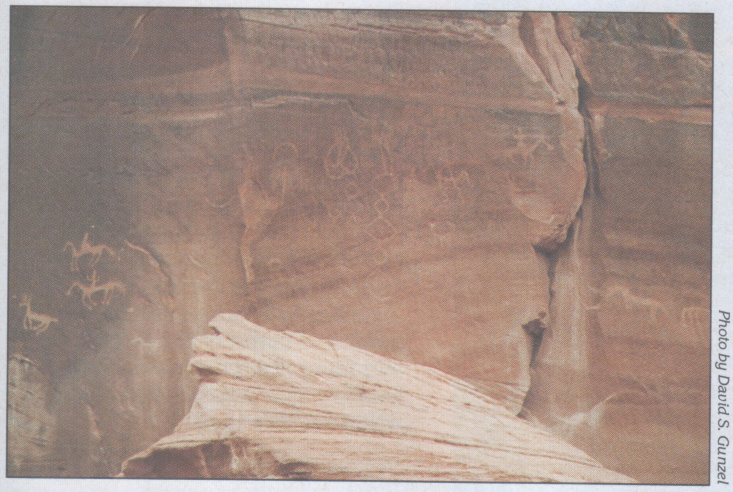


Photo by David S. Gunzel

These examples of rock art are found in Petrified Forest National Park. The petroglyphs, chiseled into the dark patina on Chinle sandstone, are found on what is known as Newspaper Rock.

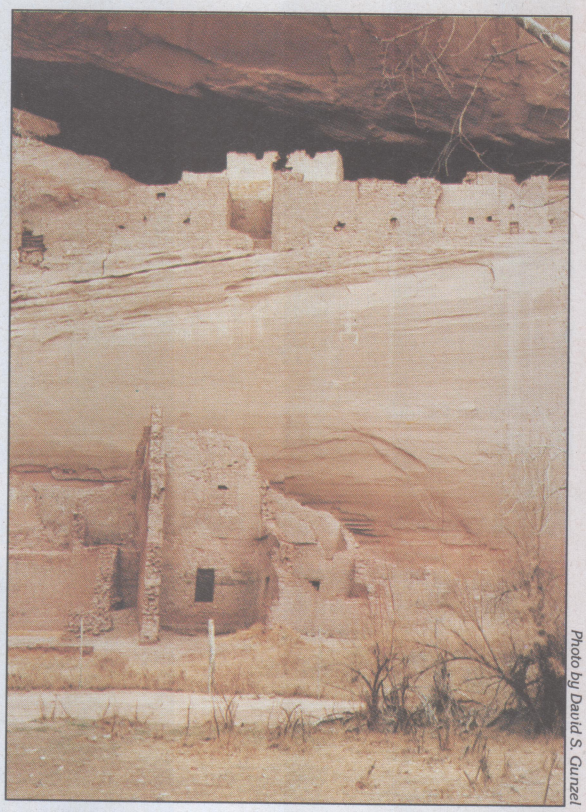


Photo by David S. Gunzel

Upper left: These are early Indian pictographs from Seminole Canyon State Park in Texas. Experts believe these artists painted a design on their hands and stamped them against the sheltered wall. **Above**: At various sites, New Mexico's Canyon de Chelly gives visitors a look at both Navajo and Anasazi rock art. Note the white figure near the center of this photo. It was probably made by the Anasazi, because it shows square images typical of the work experts believe to have been done during that era.

home. Start your search at the library. Books and magazines will lead to sites close by. For other suggestions, you might also call the nearest state park office, a professor at the geology or archaeology department of a nearby university, or a state extension agent.

Scientists have developed meticulous and important record-keeping systems for rock art. Review examples in such books as *Rock Art of the American Indians.*

Experts divide the ancient art into a variety of categories, but the two basic groups are *petroglyphs*, which were pecked or scratched into stone, and *pictographs*, which were painted on rock surfaces.

Most pictographs are black, white or red. Often several layers of both types of images are created on top of each other. The majority of the figures are animals, and many others are religious figures or humans.

Another basic difference to look for is whether the figures are profiles — creatures facing left or right — or facing head on. What is missing from the image? The lack of a weapon or ornamentation may indicate a date prior to their introduction.

An intriguing question is: What implement made an image? A sharp, pointed rock? Leaves tightly bound into a brush? A club dashed against soft clay or rock?

Note the location on a topographical map. Why did the artist choose this site? At what point in history?

The natural wear of weather and shifting soil has an impact on rock art. These threats, however, have some mitigating value. Patina, a natural darkening of the surface caused by oxidation, helps date the images. And although layers of soil may hide art, they also protect the images and hide other artifacts nearby that may indicate both *when* the image was created and *why.*

For new and old discoveries, the best protection against time is photography. Making pictures of the images takes some thought. Sunlight at the right angle brings out colors and contrasts. Dim lighting in many caves and sheltered overhangs is a challenge. If the artwork is etched, a flash unit aimed carefully can record the shadows and preserve the image accurately.

The mysteries of early American art are priceless. Unsolvable, they free us to imagine, and perhaps learn about ourselves by learning to understand the past. ✳

FURTHER READING

Ancient Texans by Harry J. Shafer (Texas Monthly Press, Austin, 1986).

The Prehistoric Native Art of Mud Glyph Cave, edited by Charles H. Faulkner (The University of Tennessee Press, Knoxville, 1986).

Rock Art of the American Indian by Campbell Grant (Promontory Press, New York, 1967).

The Rock Art of Texas Indians by Forrest Kirkland and W.W. Newcomb Jr. (University of Texas Press, Austin, 1967).

Medicinal *Plants*

By Ilil Arbel

From herbal medicine to today's wonder drugs

Summary

Many of today's synthetic drugs are derived directly from plants. Here Ilil Arbel traces the long history of medicinal plants. She also describes several examples of plants with specific medicinal properties.

Witches' brew and an alchemist wearing a tall, pointed hat covered with stars. . . . If this is the image that comes to your mind's eye when herbal medicine is mentioned, you are mistaken. Well, perhaps just a bit of the mandrake and a touch of belladonna did go into the bubbling pot in those little social gatherings during the Dark Ages, but today 40% of all medicines are made directly from plants in the United States alone.

The medicinal plants came with us on a long journey. They were used thousands of years ago, perhaps since prehistoric times. People might have seen sick animals eating certain herbs to heal themselves, and tried to emulate them. Or perhaps the search for healing plants was as instinctive in humanity as it was in animals.

In India and China, *herbals* (books about herbs and plants) were written about 2700 B.C., and much modern Chinese medicine uses age-old tradition.

An ancient Egyptian herbal was written in 2980 B.C. by a semi-legendary physician called Imhotep. Later, in 2000 B.C., five-sixths of all medicines used by the ancient Egyptians were derived from plants. Naturally much of it was considered magic, the herbalist's power to heal assumed to be given by the gods, but that did not prevent the medicines' success.

Much work was done in Mesopotamia. There is a Sumerian herbal dating to 2500 B.C., and in Assyria, tablets dating to Ashurbanipal (668-626 B.C.) claimed plants used for medicinal purposes were cultivated in the royal gardens.

Greece had the classic herbal medicine of Aesculapius, a physician deified for his work, and the scientific method of Hippocrates. There were also writings by Diocles Carystius and Theophrastus of Eresus, whose work was based on Aristotle's botanical works.

The Alexandrian School, founded in 331 B.C. attracted physicians from many countries, where they drew on ancient knowledge and the new information brought back from Alexander's campaigns in Western Asia.

In the first century A.D., the name Dioscorides is probably the greatest. He was a Greek physician who worked for the Roman army and traveled with them in the Near East, France, Spain, Germany and throughout Italy. Dioscorides was a close follower of the system of Hippocrates, but he added an enormous amount of material.

His work mentioned 600 medicinal plants, meticulously recorded with name, habitat, description, medical preparation and the effect on the patient. His book, *Materia Medica* has been the standard medical reference for 1500 years, and can still be purchased.

Rome had Pliny. Seven volumes out of his *Historia Naturalis* were devoted to the study of medicinal plants. It was not as scientific in approach as the Greek herbals, but nevertheless it was a stepping stone. Galen's work (A.D. 131-201) was more scientific. He traveled over the known world and wrote an important herbal, among many other books. His influence lasted well into the Middle Ages.

Most scientific work did not thrive in Europe during the Dark Ages after the fall of the Roman Empire. Monks did their best to preserve medicinal and herbal literature, but for 600 years little advance was made. The Jews and Arabs, though, continued the study, and kept much of the Greek legacy alive.

The situation improved as the Middle Ages progressed, and great herbals began to be written again. Around 1314 John of Gaddesden, a monk, wrote *Rosa Medicinae*, combining knowledge of Greek, Jewish, Arabic and Saxon scholars.

Good work was done in Venice, but a burst of knowledge happened only during the Renaissance. The invention of printing helped a great deal, and some of the finest works, including John Gerard's and Nicholas Culpeper's famous herbals were written in this time.

Native Americans have successfully used plants for generations, and much more could be done to match their practices with modern research.

These enchanting books can still be bought, and are truly fascinating reading material. Scientifically, however, they were not without fault, because, unfortunately, many writers of the time believed in the strange Doctrine of Signatures.

According the doctrine, each plant acted on the part of the body that it resembled in looks, as God, supposedly, made the plants with the particular idea that they should serve as medication.

For instance, William Coles, an English herbalist, wrote, "God has not only stamped upon the plant as upon every man a distinct form, but also given them particular signatures, whereby a man may read even in legible characters the use of them.

"Heart Trefoyle is so called not only because the leaf is triangular like the heart of a man, but also because each leaf contains the perfect icon of an heart and that in its proper color."

Despite this strange idea, experience taught people how to use many plants appropriately. Gardens were established and medicinal plants were even brought in from the New World.

Many medicinal plants are highly poisonous, easily confused with other plants and difficult to prepare.

The 18th and 19th centuries saw a true scientific approach, and as botany developed, and plants were classified by Carl Linnaeus, simple herbalism was replaced by medical techniques. The development of chemistry allowed scientists to isolate and manufacture chemical substances.

Synthetic drugs are useful and predictable, and the dominance of chemical medicine cannot be argued, at least in industrial countries. But as I mentioned, many American drugs are derived directly from plants. And America is behind other industrialized countries in the research of medicinal plants. Switzerland, Germany, Sweden and Japan are much more advanced. This is not because American researchers are not interested in the subject. They certainly are.

But in America, it takes millions of dollars to prove a drug safe, probably because we are more prone to restrictive legislation than any other country. It is unfortunate, because our wealth of flora and talented scientists may hold the key to many cures. Native Americans have successfully used plants for generations, and much more could be done to match their practices with modern research.

Obviously, this article is not meant to be a "how-to." Many medicinal plants are highly poisonous, easily confused with other plants and difficult to prepare. They are better left to the professionals. I only want to introduce you to a few plants that have been accepted, and used extensively, by modern medicine.



Passion Flower (Passiflora)

Passion flower was discovered in the 1660s by an imaginative Catholic friar visiting the New World. He must have been stunned by the beauty and unique shape of the large flowers on this climbing vine. It is rumored that the natives used the plant as an aphrodisiac, but the good friar saw something more spiritual in it — a symbol of the passion of Christ.

The 10 petals represent the apostles, without Peter and Judas. The corona is the Crown of Thorns. The five anthers are the Wounds. The three styles are the nails. The three sepals are the Trinity. The tendrils are the Whips of Persecution.

The friar sent the plant to Europe, where it caused quite a stir. No wonder. If the lovely symbolism had not been enough, the plant proved a great success as an ornamental, and later as a medicinal plant. The herbalists discovered that the entire plant could be used for the production of sedatives, including the delicious, golden fruit. The sedative effect relieved insomnia, headaches, neuralgia and epilepsy.

The constituents of the plant extracts are various alkaloids and flavonoids. Recent research has shown that the extracts are indeed sedative, reduce blood pressure, increase respiratory rate and decrease motor activity.

Indeed they do wonders for neuralgia, and nothing could be gentler or more effective for insomnia, not even its herbal competition, the valerian, so famous for it use against shell shock during World War I.

The valerian, a very effective sedative, is slightly addictive, while the passiflora is totally nonaddictive and has no side effects. In large quantities it may be harmful, so it should, like any other medicine, be taken only under medical supervision.

But eating the fruit is perfectly harmless. In the warmer parts of the country it is often found in fruit stands, and is not only safe, but full of vitamins.

If you plant the seeds, they sprout with almost miraculous speed, and if given direct sunlight, the vine will flower the second year. You can raise it outside in warm climates, and as a particularly lovely house plant in the colder parts of the country. The seeds are also available from many seed catalogs.



Marijuana
(Cannabis sativa)

A plant with truly a bad reputation, it has been blamed for the moral ruin of an entire generation. Though milder than other illegal drugs such as LSD or cocaine, it effects can be devastating, depending on individual reactions. It has caused hallucinations, changes in blood pressure and personality changes such as reduced motivation and a general lack of interest in life.

Some argue that it leads to further experiments with heavier drugs even if it does not affect the individual adversely. Nevertheless, the plant is now doing so much good, you might say it has mended its ways and is a reformed character.

Its native land is Asia, but for obvious reasons it has spread over a large part of the world. It grows to 4.3 m (14 feet), with dark green foliage and greenish, small flowers. Not a particularly attractive plant, but it has a long and fascinating history.

Gerard knew all about its properties, calling it the "Indian Dreamer" plant in his herbal. The emperor-herbalist Shen-Nung recommended it thousands of years ago for leprosy, among other improbable things. It is thought it was employed for the frenzied dances of Mongolian shamans. It was found in 4,000-year-old Egyptian sites. Herodotus reported that the Scythians threw the seeds on hot stones in steam baths to produce intoxicating smoke, and sure enough, evidence for the practice was discovered when archaeologists dug Scythian settlements. Galen wrote about it.

Marco Polo said the world *assassins* came from Asia Minor, where organized murderers were rewarded with *hashish*, as marijuana was called there, for their efforts.

Today, it is used for the treatment of glaucoma. It is an antibiotic against gram-positive bacteria.

Most important, it relieves the terrible discomfort of anti-cancer chemotherapy, particularly the unbearable nausea many patients had to endure before this effect was discovered. Nothing else works that well for many sufferers, and if it makes recovery time from cancer even somewhat easier to bear, for this alone I consider the plant a miracle worker.

Naturally this and other plants mentioned in this article should never be used without medical supervision.

More medicinal plants

There are many other useful and important medicinal plants, some too familiar to require elaborate description:

Foxglove (*Digitalis purpurea*), a beautiful ornamental, was used successfully as heart medicine since the 18th century.

The **opium poppy** (*Papaver somniferum*), famous as an illegal drug, but has given us morphine, an essential in modern medicine.

Quinine (*Cinchora calisaya*), which yields malaria medicine, still saving thousands of lives.

Meadow saffron (*Colchicum autumnale*), a source of colchicine, once used to treat rheumatism, now used as a research tool in genetics.

Belladonna (*Atropa belladonna*), alchemist's favorite, yielding atropine, widely used in eye medicine.

Varlerian (*Valeriana officinalis*), excellent sedative used for generations, now treats high blood pressure.

Wild roses (*Rosa rugosa, Rosa canina*), some of the best sources for vitamin C.

Dandelion (*Taraxacum officinale*), a better diuretic than the chemical ones, as it replaces the potassium that is leached out. Now also experimented on as a weight-loss agent and as a remedy for yeast infections.

We have an unfortunate tendency, in the West, to dismiss all that is old as obsolete, and assume only the modern has value. I think it is wonderful we have not done so in the field of medicine, and are wisely using our entire heritage.

It is interesting to note that the Hippocratic Oath, which all physicians take to this day, is not only named after the great Hippocrates, but is also a beautiful tie between old and new.

The opening words are, "I swear by the great Apollo, the Physician, by Aesculapius, by Hygia and Panacea and by all the Gods and Goddesses . . . " ✳

ABOUT THE AUTHOR

Ilil Arbel, formerly a technical illustrator for *Scientific American* for 14 years, has illustrated and written books on botany and crafts. She is also an illustrator for the American Museum of Natural History in New York City.



American Ginseng
(Panax quinquefolius)

The name ginseng suggests the Orient at its greatest splendor. Nevertheless, it is a native of northeastern America. The Chinese believed it possessed extraordinary powers, a true cure-all. They have been cultivating a related species, the Korean Ginseng, for thousands of years, and have almost exhausted the supplies. So tons of the medicine have been transported to China from the United States, an export worth millions of dollars.

To the traditional Chinese the plant needed a root resembling the human form. The more it looks human, the more valuable the plant.

While this sounds like superstition, amazing results came from modern research. From 1948, the Russians conducted experiments that proved without doubt that the plant improved concentration and endurance. The experiments were successfully repeated in London.

Externally applied, the ointment made from it healed wounds quickly, and internally the plant was used successfully to treat angina pectoris. Its most interesting quality is its adaptogenic effect. It helps the body return to normal in high or low temperatures and after periods of stress.



Common Evening Primrose
(Oenothera biennis)

Not really a primrose, this biennial is a native of North America. A large plant, growing to 1.8 meters (6 feet) with bright yellow little flowers. Amazingly, it does not have much of a past. American Indians used it as poultice for bruises, and had a limited use of tea made from the roots.

The part used now is the oil extracted from the plant. The list of uses, and potential uses, may sound like the claims of a quack doctor from a Wild West medicine show, but they have been proven in Europe. The plant is a source for gamma-linolenic acid, a precursor of a hormone-like substance that regulates many of the body's systems. It acts as a balancing agent for abnormalities of essential fatty acids in the production of prostaglandins. It fights coronary artery disease and reduces blood pressure. It is recommended as an alternative to hormone replacement therapy, because it relieves menopausal symptoms in a large percentage of women. It relieves PMS. It clears up skin problems and helps dried-eye syndrome.

These are the proven facts. Now for the potential medicinal uses — some controversial — which are being experimented on in England and Scotland. Evening Primrose Oil fights liver damage caused by alcoholism, so they are trying it on recovering alcoholics. Combined with fish oil, it seems to alleviate rheumatoid arthritis, and 60% of the patients involved in one study stopped using anti-arthritis medicine.

The most controversial uses are new experiments done for the potential use of the plant's oil for sufferers of multiple sclerosis. It seems to cause remissions.

All that is accomplished with few side effects — mild headaches and nausea, and occasional skin rash. It is not recommended for anyone who suffers from any form of epilepsy. Not bad for a miracle drug!

FURTHER READING

Plants of the Gods by Richard E. Schultes and Albert Hofmann (Alfred van der Marck Editions, New York, 1979)

A History of Herbal Plants by Richard le Strange (Angus and Robertson, 1977)

Plants and Man by E.L. Edlin (Natural History Press, New York, 1969)

Plants for Man by Robert W. Schery (Prentice-Hall, 1972)

Taxonomy of Vascular Plants by George H.M. Lawrence (Macmillan Publishing, 1951)

Peterson Field Guide, Eastern/Central Medicinal Plants by Steven Foster and James A. Duke (Houghton Mifflin Company, 1990)



Florist's Chrysanthemum
(C. X morifolium)

The newest, most modern sickness must be the mysterious affliction of the "sick building syndrome." Without apparent reason, people in some buildings have headaches, nausea and flu-like symptoms, but only if they stay in the building. Many scientists think this syndrome is related to indoor pollution.

They argue that our homes are filled with toxic pollutants such as formaldehyde, benzene and trichloroethylene, which have been isolated and identified many times. The gases pose a more serious problem in the tightly-sealed, high-rise office building, some of which are improperly ventilated, causing a strong concentration of pollutants.

The solution? Common plants. Various dracaenas and philodendrons remove formaldehyde and benzene from the air. Spider plants take care of carbon monoxide. But the absolute best — the one that clears air of anything you can think of — is the florist's chrysanthemum.

This is one medicinal plant you certainly may experiment with without worry. Fill the house with as many pots of this beautiful plant as you like, and the air will be clean and fragrant. They are extremely easy to propagate from cuttings, so the "medicine" would not even cost much, and all they want is a little care and a lot of sunshine.



Jimson Weed
(Datura stramonium)

This plant is shrouded in mystery. It is spread over the world — so common it is sometimes considered a weed. But there is controversy about its origin. Some claim it is native to the tropical regions of North America. Others claim it is indigenous to the Caspian Sea, from which it was distributed through Europe.

Then there is evidence that it was used by Nubians, and Gerard himself grew it in his London garden. I don't think we'll ever know.

The plant's beauty cannot be denied. It is a perennial that grows to 1.5 m (5 feet), with dark green foliage displaying the white or purple flowers to perfection. It has decorative seed pods, green when young, then turning to golden-brown.

While it sounds like the flower arranger's dream plant, I suggest avoiding it. Every part is violently toxic, and can cause hallucinations and even death. At its best it will cause your eyes to swell with a severe allergic reaction. When I cut the part I used for the illustration, I used heavy rubber gloves!

Datura has been used for generations as a medicinal plant. But the most important use was the hallucinogenic effect the plant has. In Mexico and the Southwest, it had played an important role in religious rites. In China it was considered sacred. A legend tells that when Buddha was preaching, heaven sprinkled the plant with dew.

Another legend tells that it is a native of a far-away star, and the visitors that come to Earth from this star carry the datura flower in their hands. Dioscorides mentions its highly toxic effects.

Modern medicine found better uses for this bizarre plant. It contains alkaloids that relax bronchioles spasms during asthma attacks and muscle spasms in Parkinson disease.

It also yields scopolamine, used in patches behind the ears to relieve travel sickness. This has literally changed the lives of serious sufferers from travel sickness, people who have previously been unable to travel by boat, plane or train.

On-line With Internet

The Scientist's Communications Tool

Story and Photographs by Joe Abernathy

Summary

Internet, a vast computer network, expands the ability of scientists, educators and students to communicate with one another. Now that individuals can obtain low-cost access to Internet, even those in the most remote locations can join cutting-edge scientific discussions and make use of distant libraries and research tools. Joe Abernathy tells how.

Low-cost, individual access to an important communications tool of the science community recently has become available, offering a feast of resources for the amateur scientist and those who aspire to be professional scientists.

Known as Internet, this "network of computer networks" is unlike anything else in the on-line world. It offers almost instant access to as many as 12 million people globally, and countless resources such as databases, technical reports, interactive scholarly journals, real-time international discussion groups, and remote computing facilities such as university computing centers and even the nation's supercomputing centers. It is here that the future of communications and education is being designed.

Internet: Not a Bulletin Board

Community bulletin boards and commercial on-line services fulfill an almost entirely separate function from Internet. When you call a BBS or a service such as CompuServe, you are limited to whatever that particular host computer will let you do — maybe download a new game, play a game on-line, even chat with a few other callers.

Internet will make you think of things in a whole new way. When you connect to this service, your computer becomes one of the estimated hundreds of thousands — or perhaps even millions — of machines that together create the whole. Sitting in your home, office or school, you can take direct control over any computer that is fully connected to the Internet, utilizing any resource that computer system may offer. These resources include the frontline computing power and research materials of the scientific world. The whole idea is pretty hard to grasp and accept at first, but once you get a taste of what the net has to offer, you'll never go back to bulletin boards. It's the difference between a horse and buggy and a BMW. And now, the net has even become cheaper than the traditional on-line services.

Although Internet is mentioned often in the scientific community, until recently it has been difficult to find a point of access, hard to navigate once on-line, and expensive. The very qualities that make Internet the most sophisticated on-line resource also make it the most obscure — it can take years to learn your way around this intellectual sprawl.

This article will explain what Internet is, how to get a user account, and where to find resources and support for your specific scientific projects and studies.

At a basic level, a modem and a telephone line will let your computer talk with other computers. Most modem owners are familiar with community "bulletin-board systems," or BBSs, which are generally small-scale, on-line gathering points run on the computer of a hobbyist or business person. There may be several dozen or several hundred callers associated with a particular BBS. And, there may be several dozen or several hundred bulletin boards in a particular town or city — Houston, for example, has around 400 BBSs.

What can you do when connected to these systems? Most bulletin boards offer on-line "libraries" of computer software and articles you can download to your own computer. It is usually possible to address private "electronic mail" to each of the callers of a particular system. When a number of people become interested in the same topic of discussion, they can organize dedicated "mailing lists" or "news groups," a form of public electronic mail in which everyone interested in a particular topic of discussion receives every piece of "mail" sent to a particular list. These discussion lists can and do focus on every topic imaginable, often springing up and dying away as quickly as a headline fades from the news.

Now, what would happen if bulletin board systems suddenly gained the ability to talk to each other? Say that the system operators of every bulletin board in town agreed that at midnight every night, their systems would call each other and exchange the contents of their respective mailing lists, along with electronic mail received for their system's users.

Better yet, invent a scheme so that you could also talk with bulletin boards in other cities while you're there. Now you're onto an exciting idea, and the approximate state of things some 20 years ago when the Internet's first ancestor was brought to life.

The Internet

Today, Internet has become a worldwide "network of computer networks." By early 1992, there were more than 3,000 of these networks, many of them with tens of thousands of users. Currently, you can reach an estimated 12 million people on Internet — but in truth, it is impossible to say how many computers are on the net, let alone how many people actually use it. At some large companies and research sites, for example, employees who regularly use the computer network may never realize that it is a part of the broader Internet network.

Every computer attached to every single constituent network within Internet contributes to the stature of the whole. The user of an individual workstation at the *Houston Chronicle*, for example, might (and in fact does) offer to the network community a library of materials related to journalism, available anonymously through a service known as an "electronic mail-based file server." You send e-mail to this utility as though it were an actual person, and it will respond with such

things as an index of available files or a list of recognized commands.

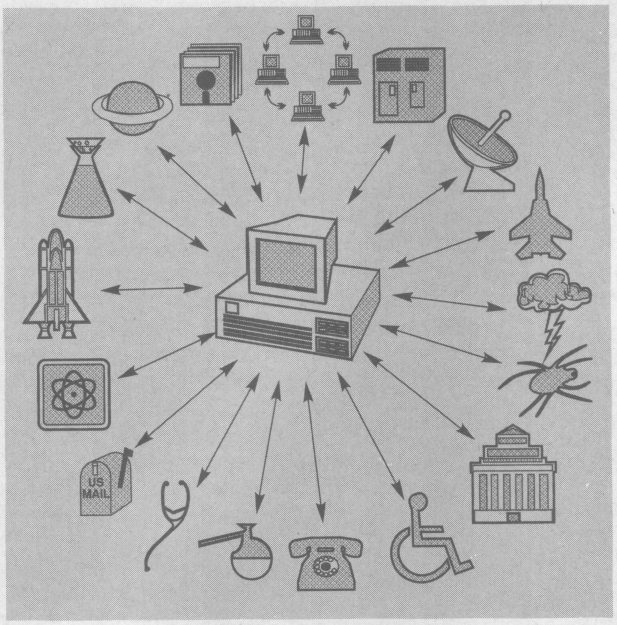
Mail-based file servers form the basis of much Internet activity, giving everyone with e-mail access the ability to download from remote libraries. A similar utility you can invoke is the "list server," which lets you take part in several thousand roundtable discussion groups on a variety of scientific, educational and recreational topics. During the cold fusion uproar two years ago, for example, an Internet mailing list sprang up that served as the primary working group for testing the claims of the Utah researchers.

Some users of the Internet have user accounts whose capabilities extend beyond electronic mail (and this well may include you, depending upon which service option you choose). E-mail access is more common because it's easy for a remote site to call a dedicated Internet server once or twice a day and forward any mail jobs that have collected. But what of the dedicated sites that have full-time, round-the-clock access to the network backbone? Accounts on these machines have considerable advantages. By "teleneting" to various addresses corresponding to specific machines, you can browse through distant libraries as though you were sitting at the distant machine, directing it to send you materials such as software, research papers, books and digital images.

You can even directly execute programs residing on distant machines. That opens up a whole world of possibilities, such as collaboratories (also called laboratories without walls), worldwide interactive chat sessions among groups of people, and the ability to remotely control supercomputers.

MUSE, the "Multi-User Simulated Environment," allows you to enter a "virtual reality," interacting with other users on-line. They assume roles in an educational artificial reality that you can help design. One scientist recently referred to MUSE as a model of how to fundamentally restructure the learning process. On its surface, MUSE looks like nothing more than a particularly fascinating on-line game.

Individual science resources available on the Internet are too extensive to catalog, although the nation's research librarians are nonetheless trying to do so. There are several thousand special-interest news groups and semi-public mailing lists available. Topics range from discussions of space shuttle flights — held by actual space scientists, during the actual space flights — to AIDS research, to the edge of artificial intelligence. Libraries range from NASA's space archives, to the Army's comprehensive collection of public domain software, to AT&T's specialized collection of numeric algorithms.



Internet provides access to unlimited scientific resources.

It is coming to this: Whereas cutting-edge research once required rooms full of books and a central location, it now requires access to Internet. What's more, anyone with sufficient desire can learn to navigate this new on-line scientific paradigm, regardless of geographical location or previous training.

It is interesting to note that one of the reasons the National Science Foundation chose to support research into inter-networking was so that scientists could have a way of using scarce supercomputer resources without having to physically travel to a supercomputing center. The experiment worked so well — Internet has become such a success — that the science foundation is now dealing with major turmoil over how to successfully divorce itself from providing network services, so that the Internet can become fully commercialized without compromising its capability as a research tool.

Barry Kort, visiting scientist at BBN Labs in Cambridge, Massachusetts, recently related a story that illustrates how the network is removing barriers between the city and the country, the privileged and the disenfranchised. Over the course of a year, Kort helped turn around the life of a 7-year-old disadvantaged youth.

"With an average of two letters per week, the transcripts of my correspondence with Abram now fill a 1-inch binder. The format of the exchange is a Socratic Dialogue, with the intent of engaging Abram in exploration of scientific material. Abram's literacy and communication skills have improved dramatically while his scholarship, attitude toward school, and self-confidence have progressed from problematic to exemplary. That computer networks can enable a professional scientist to reach into the home and life of an American child is a testament to the largely untapped potential of network technology."

How to Get a Network Account

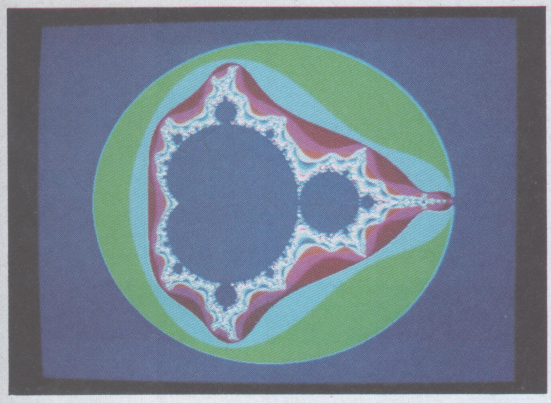
The following information will explain how to get your own account on the network, and how to find your way around once you're on-line with Internet. A list of recommended reading is also included to help you grasp the concepts of electronic mail addressing and related topics.

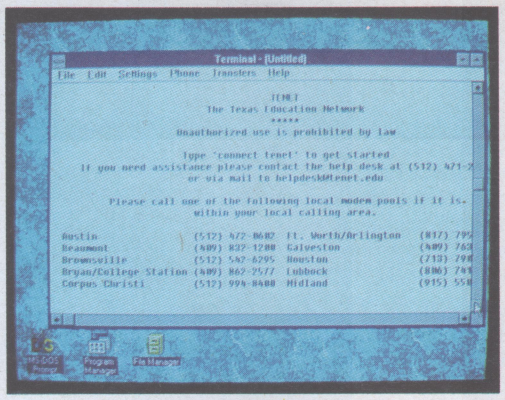
Don't worry if you have lots of questions and doubts at first. A wonderful new world awaits you, and there will be plenty of people to help you find your way. To get started, select a service provider from the list below, then work your way through the documents described in "How to Find Your Way Around the Internet."

You'll be netting like a pro in no time. And don't feel pressured to master everything at once — start by sending e-mail to me or another friend, and then try out other services one by one.

ABOUT THE AUTHOR

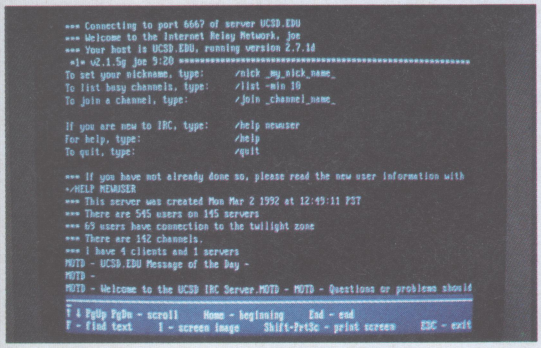
Joe Abernathy writes extensively about computer science and telecommunications. As a reporter for the *Houston Chronicle,* he has pioneered coverage of the Internet community in the mainstream press. He can be reached on the Internet at the address **edtjda@chron.com**; or on **GEnie** at **J.ABERNATHY**. Or, write to him at 6111 Beverlyhill St. #85, Houston, Texas 77057.





(Upper left) Mandelbrot set as generated by fractal manipulation program downloaded from the Internet.

(Upper right) Texas Education Network offers free Internet access to parents, teachers and students in Texas. One of many such educational services available across the USA.





(Lower left) Internet Relay Chat lets hundreds of people around the world interact in real-time on almost any scientific subject.

(Lower right) Image of Saturn downloaded from a library of space-related images on Internet.

Internet Resources

National Public Telecomputing Network is a fledgling attempt to create the on-line equivalent of television's Public Broadcasting System. NPTN offers Internet access through a community-oriented model that some observers expect to be the future of wide-area networking. Also known as the "Freenet," NPTN does not charge for access, but is very popular and sometimes difficult to access. The numbers: Cleveland Freenet, (216) 368-3888; Heartland Freenet, (309) 674-1100; Medina, Ohio, Freenet, (216) 723-6732; Cincinnati Freenet, (513) 579-1990; Youngstown, Ohio, Freenet, (216) 742-3072.

Callers to these systems are not required to reside in the host states. In conjunction with a long-distance telephone service provider (such as SprintNet or British Telecom), the NPTN can offer you full Internet access beginning at under $5 per hour.

PSINet accounts begin at $19 per month with no per-hour access charge. Incoming calls are toll-free in most parts of the United States and in some parts of the world for some accounts. Write or call: Performance Systems International, 11800 Sunrise Valley Drive, Suite 1100, Reston, Virginia 22091, (703) 620-6651.

PSI is often the best option for individual users, but some companies, rural users and larger institutions will fare better dealing with UUNET or a university-based member of the network.

UUNET (AlterNet), service begins at $2 per hour for mail or news, ranging up to $5.60 per hour for access through CompuServe, or $10 per hour for non-prime-time, toll-free access from anywhere in the United States.

UUNET is perhaps the best-connected mail gateway on the Internet, and has a library that includes every piece of public domain UNIX software in existence. Contact them at: UUNET Communications, 3110 Fairview Park Drive, Suite 570, Falls Church, Virginia 22042, (703) 876-5050.

Texas Education Network offers free Internet access to anyone involved with public or private education in Texas. Have your computer call (800) 258-3638, type "connect tenet," and you're there.

California Education and Research Federation Network, has a $250 sign-up fee that may be waived and costs $20 monthly, $5 hourly. Contact them at: CERFnet, P.O. Box 85608, San Diego, California 92186, (980) 876-2373.

Colorado Supernet, Colorado School of Mines, 1500 Illinois, Golden, Colorado 80401 (303) 273-3471. This network serves only Colorado; $2 per hour, $20 start-up fee, $20 per month minimum.

Metanet, requires a $15 registration fee, a $20 per month flat fee and no per-hour charges in the Washington, D.C., area; $6.75 per hour elsewhere in the U.S.A. via SprintNet. Fees are higher overseas. Check for level of Internet connectivity and specific services. Metasystems Design Group, 2000 North 15th St., Suite 103, Arlington, Virginia 22201, (703) 243-6622.

CICNet serves the states of the Big 10 schools. Pricing is being restructured, but a CICNet administrator promises that the new structure will specifically contain provisions to appeal to the readers of *Science PROBE!*. Contact CICNet, 2901 Hubbard, Pod G, Ann Arbor, Michigan 48105, (313) 998-6103.

CONCERT offers network accounts to North Carolina residents, with a $100 installation fee and connect charges beginning at $25 per month. Contact Julie Ann Sellers at (919) 248-1466.

Netcom Online Communications Services is located in the San Francisco Bay area but will accept callers from anywhere. They also offer personal accounts for $17.50 per month with no per-hour charges. Users paying with MasterCard or Visa receive service for $15.75. Other levels of service are available for businesses. To register, have your computer dial (408) 241-9760; type "guest" at the login prompt; no password is needed. Netcom, 4000 Moorpark Ave., Suite 209, San Jose, California 95117, (408) 554-UNIX.

For those who read Swedish, an Internet service provider, Olle F. Wallner of SwipNet, offers low-cost access to amateur and/or young scientists in Sweden. SwipNet AB, P.O. Box 6048, S-164 06 Kista, Sweden. Esbogatan 14. (+46) 8 92 40 40.

Various levels of Internet access are available from several dozen free or low-cost public access UNIX systems around the nation. To receive a list, send a self-addressed, legal-size envelope, stamped with 50 cents in postage, to: Joe Abernathy, 6111 Beverlyhill St. #85, Houston, Texas 77057. Include $1 to cover duplication costs.

The conditions of access to Internet vary widely from place to place and from provider to provider. This is because the net was conceived as a tool meant only for researchers, and only recently has become available to others. The good news is that everybody, everywhere can now get an account, although some will pay more than others.

The first place to request an account is from the computer science department of any nearby college; this is likely to be the cheapest source. Some university-based Internet members also provide accounts to the public or to area businesses.

Otherwise, you should choose from one of the following services, depending on which is most attractive given your geographical location — regional networks such as CERFnet and TENET provide service only to people or organizations in their region. ✳

Helpful Books

Using UUCP and Usenet, $17.95, Nutshell Handbooks, O'Reilly & Associates Inc., 632 Petaluma Ave., Sebastopol, California 95472. Explains the fundamentals of the real "grass roots" Internet, and the distributed newsgroups that are collectively known as "news" or the "Usenet." This book is a must to fully understanding the net.

A Directory of Electronic Mail Addressing & Networks, $27.95, Nutshell Handbooks, O'Reilly & Associates Inc., 632 Petaluma Ave., Sebastopol, California 95472. Explains the mysteries of electronic mail addressing, and gives specific information on how to send mail to a user on most of the 3,000 some-odd networks that together comprise the Internet.

Learning the UNIX Operating System, Nutshell Handbooks, O'Reilly & Associates Inc., 632 Petaluma Ave., Sebastopol, California 95472. You may need one or more basic-level books on how to use UNIX. This particular book is a favorite, because it is easy to navigate, even though other volumes offer more detail. In general, any such tutorial that contains a command summary and speaks to your current level of sophistication will suffice.

The Matrix — Computer Networks and Conferencing Systems Worldwide, $50, John S. Quarterman, Digital Press, 12 Crosby Drive, Bedford, Massachusetts 01730. Quarterman's 700-page treatise, is the only comprehensive source of information on the global computer network.

How to Find Your Way Around the Internet

There's no user manual for the Internet — there's not even an index. In fact, one of the primary pursuits of members of the computer underground is hacking about the net to see what's there.

Fortunately, you are spared from such stumbling about. To compile a working index of nearly everything worthwhile on the Internet:

- Robert Elton Maas of Stanford, California, maintains a set of documents telling how to find indexes to the various services available on Internet; an index to the major tutorial documents regarding use of these services; and an assortment of how-to documents. To get the MaasIndex, send electronic mail to the address fileserv@shsu.edu with a line in the body of the message saying:
  SENDME MaasInfo.TopIndex*
- The Internet Resource Guide describes all of the high-level resources available on the network, such as supercomputing facilities and research laboratories. To get it, send electronic mail to info-server@nnsc.nsf.net. In the body of the message, type:
  Request: resource-guide
  Topic: resource-guide-help
  Request: end
- To get the Internet List-of-Mailing-Lists (hundreds of discussion groups to which you can subscribe), send e-mail to the address: mail-server@nisc.sri.com with a line as follows:
  send netinfo/interest-groups
- The Bitnet Network Information Center (BITNIC) offers a variety of valuable resources, including a remote database of scientific and other information that can be accessed by electronic mail. Send electronic mail to: listserv@bitnic.bitnet with this line:
  help
- Elliot Parker maintains a Computer Network bibliography containing pointers to print and on-line sources for beginning computer networks. To request it, send e-mail to this address:
  comserve@rpiecs.bitnet
  with a message body saying:
  send compunet biblio
- "Mining the Internet" is a training package available free of cost through the University of California. Author Gee Lee can be contacted at the address:
  gblee@ucdavis.edu
- The Army's SIMTEL20 Software Archive at the White Sands, New Mexico, Missile Range is one of the world's largest collections of public domain and shareware software for the IBM, CP/M, UNIX and Macintosh operating systems. To get access, telenet to 26.2.0.74, or send your request electronic mail to Elwood Baas at:
  ebaas@wsmr-simtel20.army.mil
- The Archie archive server listing service at the McGill School of Computer Science is a central database for information about various archive sites — a kind of index into the indexes. To access Archie, telenet or rlogin to:
  quiche.cs.mcgill.ca (132.206.2.3)
  as user Archie. You can also receive a copy of the manual by sending mail to:
  archie-admin@cs.cgill.ca
- Cleveland Freenet — Offers a point of access into the National Public Telecomputing Network, which is expected to evolve into the PBS of the online world. Telenet to:
  freenet-in-a.cwru.edu
- Geographic name server — Offers info by city or area code concerning population, latitude, elevation and other geographical information. Telenet to:
  martini.eecs.umich.edu 3000
- National Weather Service — Telenet to 141.212.196.79 3000 . Offers forecast for any city, current weather for any locale and other information.
- Webster — Offers dictionary, thesaurus and spelling checker. Telenet to:
  decoy.uoregon.edu 2627
  Type HELP once on-line.
- IRC Telenet Client — Telenet to 128.2.54.2 to get access to Internet Relay Chat, a worldwide interactive chat system dealing with everything from the business of science to the computer underground.
- Ham Radio Callbook — Telenet to 128.2055.32.4 2000 . National ham radio call-sign callbook.
- A wide variety of images and space-related information is available. A document describing how to find and access these services is available from Jonathan Leech at the address leech@cs.unc.edu . Among the services Leech covers are the NASA Ames archives, SpaceLink, the National Space Science Data Center, astronomical databases, astronomy software collections, orbital element sets, planetary maps, and LANDSAT and NASA photos.
- The Directory of Scholarly Electronic Conferences is available by send electronic mail to listserv@kentvm.bitnet containing the message:
  send acadlist readme
  send acadlist index
- How do you find the e-mail address of somebody you know is on the Internet? Send electronic mail to mail-server@pit-manager.mit.edu with "send usenet-addresses/name" in the subject or body of the message. Substitute the electronic ID of the contact person for "name."
- If the person you wish to locate is a site manager or other "official" person, you can determine their mail address by sending a message to:
  SERVICE@NIC.DDN.MIL
  with "WHOIS <name>" as the subject line. (Substitute "name" with the actual person's name.)
- Users who only have e-mail access to Internet still can enjoy FTP file transfer capabilities, which usually are reserved for users with full access. Send mail with the word HELP to:
  FTPMAIL@DECWRL.DEC.COM

Summary

When the tiny side of nature is too big for photography through a microscope, you can use an ordinary camera and inexpensive attachments. Brian R. Page describes three of these economical close-up photography methods.

CLOSE-UP PHOTOGRAPHY ON A BUDGET

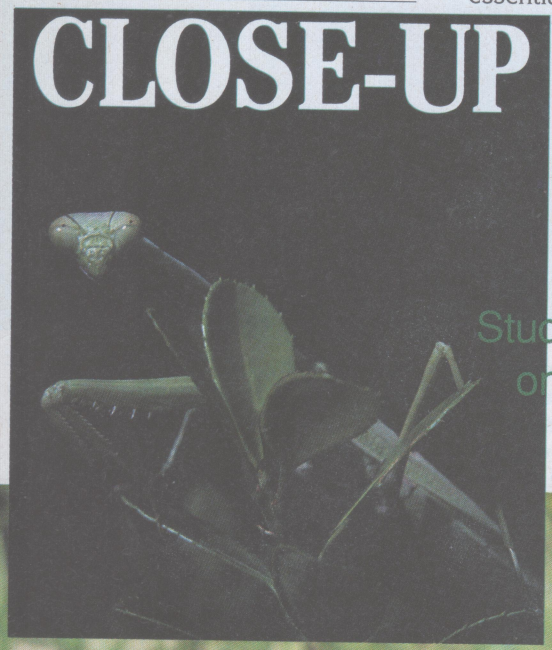
Story and Photographs by Brian R. Page

Study insects and plants, or simple beauty with one of the best tools of science — a camera.

There is a little-known world of nature rich in varied detail. Life underfoot, the tiny side of nature, is a place of intense competition, stalking animals and sudden death. Nature on this scale is wide open for exploration by the amateur naturalist. To go on safari, just get down on your hands and knees.

Close-up photography is often essential to document your discoveries and observations there. Fortunately, if you already own a 35-mm single-lens reflex camera it can be adapted for close-up work without great trouble or expense.

A single-lens reflex camera allows you to compose a picture while viewing through the actual lens used to expose the film. By contrast, many popular cameras use a separate view finder or range finder. These cameras are not suitable for



Left: Praying mantis (family Mantidae). **Below**: Kathy Page records floral details.



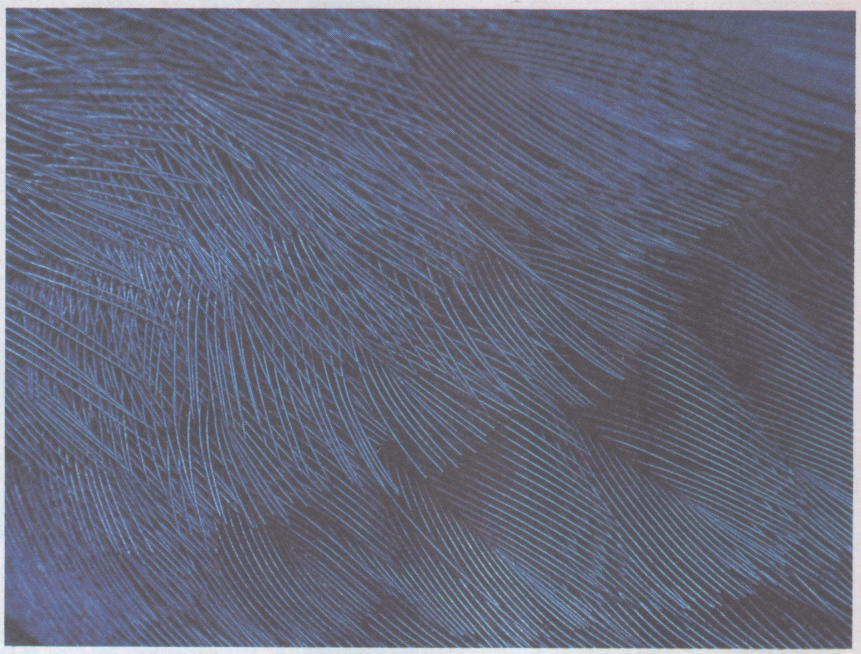
Table 1: Supplementary Lens Subject Area

50 mm Camera Lens

Diopter	Infinity	0.6 m (2 ft)
+1	71 x 48 cm	23 x 15 cm
+2	36 x 23	17 x 11
+3	24 x 16	13 x 9
+4	17 x 11	11 x 8

105 mm Camera Lens

Diopter	Infinity	1 m (3.3 ft)
+1	34 x 23 cm	14 x 10 cm
+2	17 x 11	10 x 7
+3	11 x 8	8 x 5
+4	8 x 6	6 x 4



Right: Feathers from an Indigo bunting (*Passerina cyanea*) photographed at 2.5x life size with a 55-mm lens on bellows and Kodachrome 64 film.

close-up work because, at close range, the view finder does not allow you to see exactly what is in front of the camera lens.

Professional photographers often use a special *macro* lens to get close to their subjects. Unfortunately, macro lenses can be quite expensive. Similar results can be obtained by an amateur without laying out a lot of cash for new equipment. In this article I describe three ways of making close-up photographs — to within a few inches of your subject.

Supplementary Lenses

The easiest way to get started in close-up photography is with a set of supplementary lenses. Supplementary lenses are simply low-power magnifying glasses mounted in a threaded ring (like a lens filter), which screws on to the front of your camera lens. A set usually consists of three lenses. The magnification power of these lenses is measured in *diopters*. The three lenses in a set are +1, +2 and +4 diopters. Using a supplementary lens is like fitting your camera with corrective eyeglasses. The purpose is to make a "far sighted" lens "nearsighted."

When you are down on your hands and knees, it is handy to know how much subject area is covered when using each lens. For that information, I refer to a table that I carry along in my camera bag. (See Table 1.) I usually use supplementary lenses with either my 50-mm "normal" lens or a 105-mm short telephoto. The table lists the size ranges of the subject area for +1, +2, +3, and +4 diopters when the camera lens is focused at infinity and also the size of the subject area when the camera is focused at the its closest focusing range.

Using my 50-mm lens focused at infinity with a +2 supplementary lens, I can photograph an area of 36 by 23 centimeters (14 by 9.75 inches). Without changing the supplementary lens, I can adjust the focusing ring on the 50-mm camera lens to its point of closest focus and photograph an area 17 by 11 cm (6.75 by 4.5 in).

When using supplementary lenses, the normal focusing adjustment is used to vary the dimensions of the subject area. Real focusing of the image is done by moving the camera. As you watch through the finder, move the camera back and forth until the subject is properly focused.

Because depth of field decreases as magnification increases, even the slightest movement causes blur. Therefore, it pays to use the smallest aperture possible. (A small aperture is indicated by a large *f* number.)

This will usually be a number such as *f*/16 or *f*/22. However, use of a small aperture means that plenty of light must be available. You need either bright sunlight, a high-speed film, or flash.

Figure 1 on the next page shows a bracket I use to hold my camera and a small electronic flash unit. The flash is permanently pointed to the area 5 cm (2 in) in front of the camera lens. This is where the subject appears in proper focus. To calculate the aperture setting, I use the *guide number* of my electronic flash. The guide number, divided by the distance between the flash and the subject, gives the aperture or *f*/stop. In our case, we already know the *f*/stop. We want to use *f*/16. So we can divide the guide number by 16 to produce the flash distance.

My small electronic flash has a metric guide number of 6 when used with Kodachrome 25, a slow, fine-grain color slide film. The guide number 6 divided by 16 gives a quotient of 0.375 meter. Thus, using Kodachrome 25 and an aperture of *f*/16, I must position the flash 37.5 cm from the subject. That's the job of the bracket.

The camera attaches to the bracket via its tripod socket. The flash is held on with rubber bands. An extension cord runs between the PC socket on my camera and the cord of the electronic flash. Finally, a +4 diopters supplementary lens goes on the front of the camera lens, and I set the aperture to *f*/16. Now I am ready to go hunting.

If your electronic flash has an automatic mode, it is a good idea to disable it. In automatic mode, the flash senses the brightness of its light during the flash and makes corrections based on the reflectivity of the subject. Be sure your flash is switched to manual mode.

If you do not have an electronic flash, use a higher speed film with an ISO rating of 64 for slides or an ISO of 100 for color negatives. Bright sunshine easily permits an aperture of *f*/16 in most cases. You

CREATING A TABLE OF FLASH DISTANCES

This BASIC program may be used to create a table of flash distances depending on the degree of enlargement.

If you have extension tubes rather than a bellows, you may wish to modify the program. The FOR-NEXT loop between lines 90 and 130 varies the magnification. Because the magnification is fixed for a given extension tube, you may wish to replace variable M with F to vary the aperture from 1 to 22.

Execution of the BASIC program results in Table 2. Flash distance is listed both in centimeters and inches. With this table, I can routinely set my camera lens to *f*/16 (for greatest depth of field) and vary the magnification as required to suit my subject.

```
10 REM PROGRAM TO DETERMINE FLASH DISTANCE WHEN USING A BELLOWS
20 CLS
30 INPUT "Enter metric guide number for film/flash combination";MGN
40 INPUT "Enter F-stop setting on lens";F
50 CLS
60 PRINT "  FLASH DISTANCE TABLE FOR FLASH GUIDE NUMBER"MGN"AND F-STOP"F
70 PRINT
80 PRINT ,"MAG","CENTIMETERS","  INCHES"
90 FOR M = 1 TO 3.5 STEP .2
100  DISTANCE = MGN / (F * (M + 1 ))
110  CM = DISTANCE * 100:INCH = CM / 2.5
120  PRINT ,M,CM,INCH
130 NEXT M
140 END
```



A 50mm lens mounted backwards on a Nikon F3 using an inexpensive reversal ring.

Table 2

FLASH DISTANCE TABLE FOR FLASH GUIDE NUMBER 12 AND F-STOP 16

MAG	CENTIMETERS	INCHES
1	37.5	15
1.2	34.09091	13.63636
1.4	31.25	12.5
1.6	28.84615	11.53846
1.8	26.78571	10.71429
2	25	9.999999
2.2	23.4375	9.374999
2.4	22.05882	8.823528
2.600001	20.83333	8.333333
2.800001	19.73684	7.894736
3.000001	18.75	7.499999
3.200001	17.85714	7.142856

Printout produced by computer program above.

can even use the built-in exposure capabilities of your camera. The use of supplementary lenses does not change the way your camera adjusts exposure.

Supplementary lenses are a great way to get started in close-up photography. A set should cost around $50. The flash bracket, of course, is optional, but can be easily made with scrap lumber.

Reversal Ring

Like a supplementary lens, the reversal ring attaches to the front of a normal camera lens. It screws in just like a filter. However, unlike a supplementary lens, a reversal ring is simply a ring. It has no glass.

One side of the reversal ring is threaded to fit the front of a camera lens. The other side of the ring is a bayonet mount that mates to the camera. With a reversal ring, the camera lens can be attached backwards on the camera. When attached like this, an ordinary camera lens becomes a close-up lens. A 50-mm lens covers a subject area of about 5-8 cm (2-3 in). This is comparable to the +4 diopter supplementary lens.

Size is the great advantage of reversal rings. When I am hard-pressed for space or weight — like on a back-packing trip for example — and do not expect to make close-up photographs, I leave my supplementary lenses and take just the reversal ring. Then if some irresistible subject crosses my path, I can usually manage.

A significant disadvantage is that when the lens is reversed, the camera cannot keep the aperture wide open (at its smallest *f* number) while I compose a photograph. If I stop down to *f*/8 or *f*/11, the view through the camera grows considerably darker.

A variety of rings designed for most popular cameras is available from Edmund Scientific for less than $20 (101 East Gloucester Pike, Barrington, New Jersey 08007-1380).

Bellows and Extension Tubes

Neither supplementary lenses nor reversal rings can record an image on film that is larger than life size. To get this close requires some specialized equipment.

An ordinary camera lens may be used to create life size (1:1) images, as well as enlargements two or three times actual size. All you have to do is increase the distance between the camera lens and the film.

Think of a camera lens as a projection device and the film as a theater screen. As the distance between the lens and the screen increases, the projected image size grows larger. There is, however, a price to pay for this growing magnification. First, the distance between the camera lens and the subject sharply declines. Maximum distance becomes something on the order of a few centimeters. Second, the intensity of the projected image dramatically decreases. A given amount of light is spread over a larger area. Finally, just as with supplementary lenses, the depth of field becomes extremely shallow.

Two devices are commonly used to provide the greater separation



The bracket is made from a piece of lumber. The edges have been routed to create a track upon which may ride a subject platform. The bellows is attached with 1/4-inch screws in its two tripod sockets. A subject is placed on the platform. The flash is positioned to point at the subject just in front of the lens.

between the camera body and the camera lens: extension tubes and bellows. Extension tubes simply snap into place between the camera and lens. One end of the tube has a bayonet mount for the camera. The other end attaches to the back of the normal lens.

An extension tube extends the lens to a single predetermined distance. The degree of image enlargement depends only on the lens used and the length of the tube. A bellows, on the other hand, works like a variable extension tube. This variable distance determines the degree of enlargement.

Each extension tube is labeled with a magnification factor for a normal lens. A bellows has a magnification scale marked on the rack.

Exposure calculation for extension tubes and bellows is somewhat more complicated than that for using supplementary lenses. Most notably, the aperture or *f*/stop setting on the lens is no longer an accurate description of the real aperture.

When a lens is extended with either device, the *effective aperture* of the optical system must be computed according to this formula:

$$EA = f * (M + 1)$$

where:

EA = Effective Aperture

f = *f*/stop or aperture setting on the camera lens

M = Magnification

For an extension tube, the magnification is a constant. With a bellows, this value depends on how far the lens is extended.

Often the only practical way of illuminating subjects for bellows and extension tubes is through the use of electronic flash units. When calculating flash distance the effective aperture is used, not merely the aperture setting on the lens. This distance is found with the formula:

$$\text{Distance} = \text{Guide Number} / \text{Effective Aperture}$$

A 2x enlargement with a lens aperture of *f*/16 and an ISO 64 slide film used with an ordinary electronic flash results in a flash distance of 25 cm (10 in).

Use of a bellows requires careful work. Depth of field is severely limited. Focusing must be done with the camera lens set at its widest aperture. Only then does it pass enough light to see the subject clearly. The wide-open aperture, however, presents a dilemma.

Depth of field is at its shallowest with a wide aperture. If you stop down the lens to *f*/16 to gain some depth of field, you can no longer see the subject clearly. The only solution is to focus with the lens aperture wide open, carefully adjust the aperture to *f*/16, take the photograph, and wait for the film to be processed.

To simplify use of a bellows, I recommend either a standard photographic copy stand or a bracket similar to the photo above. This bracket securely holds the camera and bellows. It also has a sliding base to hold a subject in front of the lens. A removable cross arm holds two electronic flash units. The flash units are positioned to provide the proper illumination for a 2.5x enlargement with my camera lens set to *f*/16. If I use another magnification, I reposition the flash units.

Close-up photography can be addictive. Once you begin to notice the small details in nature, you'll find yourself down on your hands and knees more often. These explorations can even be dangerous, like the time I attempted to photograph hornets in the wild. All I received for my effort was a painful welt and some first-hand experience with swarming social insects. ✳

FURTHER READING

Photographing Nature by the editors of Time-Life Books (Time-Life Books, 1974). This book is one volume of the Time-Life series on photography. It includes a chapter on close-up photography using a variety of techniques.

Life on a Little-known Planet by Howard Ensign Evans (University of Chicago Press, 1984). This is a splendid introduction to entomology, the study of insects — ideal subjects for close-up photography.

ABOUT THE AUTHOR

Brian R. Page was once a newspaper photographer. Now he's a data processing manager enjoying the combination of aesthetics and technology of his leisure time photography.

Smoking Lady in a Black Dress

The 1991-92 Eruption of Mount Etna

Photos and Text
By Stephen James O'Meara

Summary

On December 14, 1991, Mount Etna, Europe's tallest and most active volcano, began its 10th major eruption this century. Five days later, lava cascading down a steep valley wall had covered a broad plain and was heading toward populated regions. At the request of Franco Barberi, president of the National Volcanic Group of Italy, construction of a containment barrier began January 1, 1992. One week later, amateur volcanologist Stephen James O'Meara arrived in Sicily to document the drama.



On the previous page: Strombolian activity on Mount Etna. **Above**: Mount Etna from the air.

From the Air

Etna looks down on Catania, Sicily, like an angel from hell. Wings of steam flow from summit craters, sending moist white plumes down rugged slopes. High snow fields hug dark cones that trickle across Etna's neck. And a powder-blue haze veils sun-bleached cities that stain its black coastal skirt. All told, it looks as if heaven is melting.

I'm a stranger in Sicily for one hour; Rosanna Velardita, a spirited geochemist at the volcano institute, befriends me. With island kindness, she arranges my lodging, drafts an itinerary, and introduces me to Sonia Calvari, a field geologist who will guide me tomorrow around the volcano. Meanwhile, I am simply to enjoy this sooty seaside metropolis of former baroque splendor.

Sonia arrives at the institute at 8 a.m. sharp, and we ready our gear. Some checklist items: cameras, film, sample bags, rugged boots, water, ice pick, helmet, goggles and gas mask.

The trek begins at 1,000 meters (3,250 feet) on an earthen barrier constructed by the civil defense to contain the lava now threatening Zafferana Etna, a town of 6,000 people. Escaping the noise of bulldozers, we follow a path through pungent scrub pines and intercept a jumble of lichen-covered woolly mammoth molars. Sonia explains that it's really a 1,700-year-old *Aa* lava flow (flow that has a jagged, blocky surface).

Soon the smell of fresh lava fills the air. My lungs fill with smoldering dust as Sonia advances up a 6-meter (20-foot) face of a day-old Aa flow. Halfway up my fingers loosen a rock, and then sink into soft gravel. *Ouch!* Heat rushes out from the sand, and days later my fingers bear the temporary white scars of singed flesh (a needless reminder that I left my gloves in the car).

ABOUT THE AUTHOR

Stephen James O'Meara, an associate editor of *Sky and Telescope* magazine, is well-known among fellow amateur astronomers for his remarkably sharp visual acuity. O'Meara was the first person to see Halley's comet during its 1985 return. Last year, asteroid 1984 UQ was named 3637 O'Meara in his honor.

Now less one glove, Sonia plows ahead. With each step, a small puff of smoke rises from her shoes. An instant later, there's a smell of burning rubber.

As we near the newest lava flow, the wind shifts and our bodies begin to bake from the effects of the lava's intense 800+°C (1,500°F) heat. We cannot walk close enough to get a sample; so we simply stand and admire this creation.

A once verdant valley lies covered by a molten glacier topped with jagged gray rocks. Before us, a hill has been stripped of life. The lava skin is lacerated, exposing an orange core. Sizzling boulders tumble onto the valley floor, smash like crystal and die in a puff of smoke and flame.

Sonia looks sad. She tells me that before the eruption, this valley was the most beautiful region on Etna. Now it has changed. I understand only because lava has robbed me of earthly treasures in Hawaii. But that is the way of volcanoes, to recycle land, life and death.

As we climb down the day-old flow and step back onto 1,700-year-old lava, we feel as if we've stepped from hot coals onto ice.

The Erupting Vent

Antonio Ritzo will guide us to the erupting fissure at 2,400 meters (7,874 feet). Carrying minimum supplies, we start our slow march. It is not the death-defying, rope-swinging journey I feared, and we reach our destination in an hour and a half. A thunderous roar greets us as we step onto an open plain. Suddenly a thick plume flies above the valley wall before us. The sound of Etna hits our ears with a steady rhythm, like the ebb and flow of tidal waves.

Ger Huybers of Velo, Holland, joins us. When he hears the mountain's report, he stops and shakes his knees in mock fright. Then I see it: Mount Etna bleeding. A red river pours from an open artery high in the valley wall and cascades down a steep ice-dappled slope. A molten soup brews on the valley floor where lava has spilled for the last month. For 6.4 kilometers (4 miles) the river branches and joins, branches and joins. It's an indecisive convoy of molten rock.

Above the main eruptive fissure, a black "den" spews smoke and fire. An occasional *thud* breaks the rhythmic breathing of the venting gas as magma slams into its earthen ceiling. Countless tongues of lava fly through a blow hole, then twirl and dance in the escaping gas. Their fluid acrobatics are immediately scorned by a hellish roar. Over and over again the scene repeats. How easy it would have been for our ancestors to believe in fire-breathing dragons. Take, for example, these lines from *Beowulf:* "The breath of the dragon billowed from the rock \ in a hissing gust; the ground boomed."

Like all lava seekers, the unexplainable longing to touch the flow, to feel its heat and to smell its aroma, overpowers me. Huybers, too, experiences this urge. Our eyes scan the valley walls for pos-

PLAYING WITH FIRE

Eruptions of Mount Etna are not rare. In fact they're quite common; the volcano has erupted about once a year for the last 20 years. Usually the activity is confined to the volcano's summit area. But every now and again fissures open down slope and send rivers of lava cascading toward villages and towns.

On January 10, Stephen James O'Meara interviewed Franco Barberi, president of the National Volcanic Group of Italy, about the eruption and the creation of the earthen barrier.

Science PROBE!: How serious is this eruption?

Barberi: It's a rather serious eruption. The one in 1983 lasted longer, 131 days, but that's not what matters. The most critical parameter is the output rate of lava. In 1983 it was less than 10 cubic meters per second. This year, after one month, we have already more than half of the 1983 volume of lava. So far, there's no evidence the present eruption will stop soon.

Science PROBE!: To date, has this eruption caused any significant damage?

Barberi: There's been about $3 million (U. S.) in damage already. Mainly, lava has destroyed the region's water system, a 700-meter-long tunnel in the mountain. The cultural part of the valley has also been destroyed. It was a rich agricultural area with many fruit trees and vineyards.

Before we constructed the barrier, the potential for damage was much higher, especially in the town of Zafferana Etnea. More important, the erupting vent is on a very famous fracture made in 1729 that opens down slope. If that happens, more cities will be threatened. So we're concentrating our attention on the erupting vent and the ancient fissure. We've set up automatic cameras to survey the fissure, which we monitor constantly from a large screen here in the office. Even during the night, we have automatic observation with infrared cameras. In case of an emergency, the Civil Defense has already prepared an evacuation plan.

Science PROBE!: Who made the decision to build the barrier?

Barberi: On January 1st, I suggested to the Civil Defense to build a barrier, because the town of Zafferana Etnea was threatened by lava. Given the output rate, we knew the flow could easily reach 10 to 20 kilometers. The morphology was so clear. Once out of Valle del Bove and Val Calanna, there would be no stopping the flow. The lava would have flowed down a steep slope. Two kilometers more and it would have hit houses.

We use computers, something relatively new, to simulate the flow's path. It's a rather simple program. First, we digitize the region's morphology using topographical maps. Then we fed the computer certain parameters: the location of the vent, the amount of lava being erupted, the velocity of the flow, and the physical and chemical composition of the lava. Interestingly, what we observe in the field fits the simulation's most probable solution.

Science PROBE!: How long did it take before construction on the barrier got under way?

Barberi: Work started that afternoon on January 1st. It took a week to complete. The most urgent part of the barrier was completed in four days — that's working all day and night. We're still working on it.

Science PROBE!: In 1983 a lava flow from Etna was successfully diverted. At the time, was there any concern among the public as to where the flow might ultimately end up? In other words, did you save one town at the risk of losing another?

Barberi: Yes, in 1983 we did divert lava but not in the way you described. We started one month after the eruption began, but by then it was too difficult to build a containment barrier. The idea then was to interrupt the flow — to cut a channel to divert lava into an uninhabited area already destroyed by lava flows. Some argued it was a violation against nature. They were happy when the lava topped our wall. Finally, the wall was exploded and we diverted part of the flow front into a channel that we dug. We created an *artificial* flow, which slowed the advancement of the main flow.

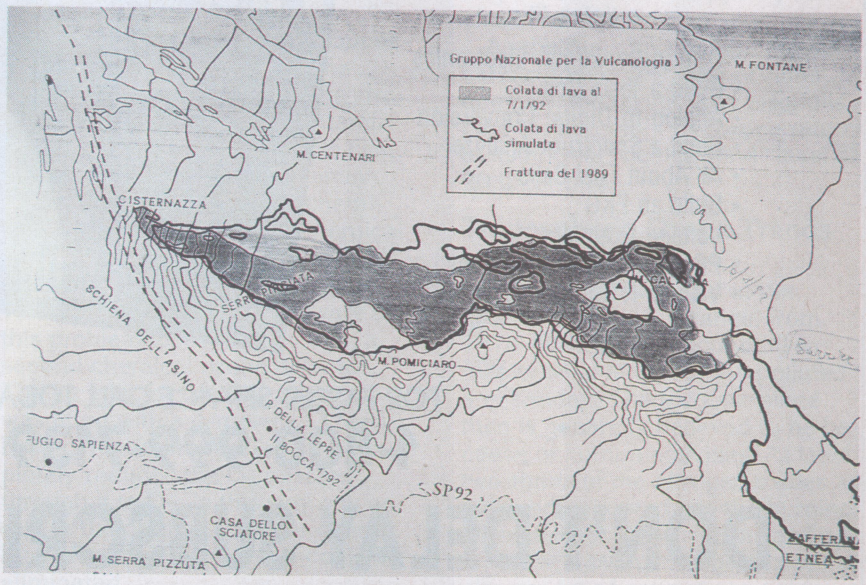
With the current eruption, our aim is not to divert but to prevent and to contain. The barrier we constructed is 20 meters high and 225 meters long. This time we are making a small contribution. Even if the lava does not reach the barrier this time, there will still be future eruptions and threats. So our barrier is permanent protection for the town.

Science PROBE!: I read or heard that the army is going to bomb the lava flow. Should I assume that's a rumor?

Barberi: Yes, the story of bombing is false. Someone heard about the "intelligent" bombs used during the Gulf War. (He laughs.) So it was assumed that if these bombs are so intelligent, maybe they can stop the lava flow.

sible access routes. But there are none. All are too steep and icy for climbing without pick and crampons. The erupting vent is located on the inside wall of the steepest and most dangerous valley incline. For safety's sake Sonia pleads that we not even try. There is no argument. We wisely heed her warnings and acknowledge our limitations. Perhaps tomorrow will be different. Maybe there's another route?

Whether I succeed tomorrow is no longer an issue. My main goal has been accomplished. I have seen Etna erupting and have walked on her young skin. For these things I am grateful. It makes no sense to test the limits of the volcano further. No one will ever be more powerful than a volcano, at least not in body. Besides, to humble oneself before creation is the ultimate in respect. ✳

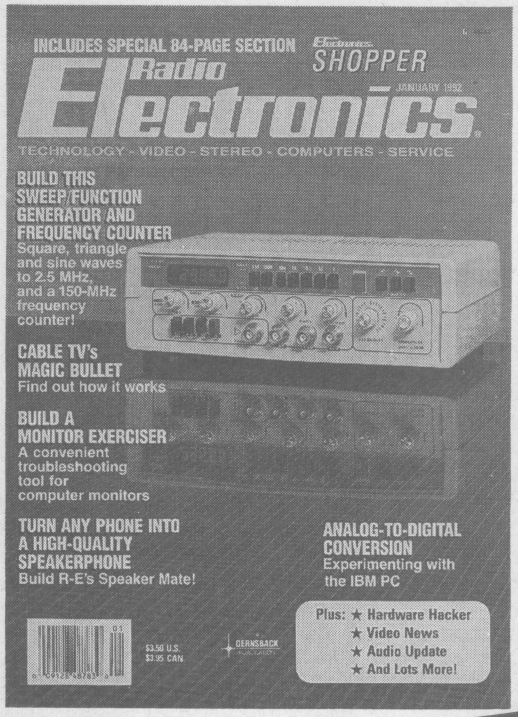


Computer-generated map showing predicted lava flow movement (solid black line) and actual lava flow movement (shaded areas). Note position of the barrier. If the lava gets beyond this point, there's no stopping it.

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WAVES, WAVES, EVERYWHERE.

By Joseph J. Carr

Waves are important because much of our physical world is either made up of waves or phenomena that behave in a wave-like manner.

Sound is formed by waves propagating through air and other substances, and "sound wave" is a part of everyday language. Electromagnetic radiation, such as light, radio and television signals, is propagated in the form of waves. Quantum physicists discovered during the first thirty years of this century that certain features of the "micro world" of atoms exist in what were called "probability waves." If certain mystically inclined scientists of today had their way, all of reality would be seen as *wave-like*!

But just how do waves behave? Sound waves are an ideal way to experiment with waves, since they're easy to produce and (at normal listening levels) perfectly safe. In this article, we'll examine some basic principles of waves. Then we'll describe the construction of a sound pipe that you can use to perform experiments with sound waves.

The Basics of Waves

The usual way to study waves is to start with a *sinusoidal* or *sine* wave such as the one in Figure 1. A sine wave is one that varies above and below a "resting state" or *base line* in a symmetrical, periodic fashion. A sine wave rises from the base line and smoothly increases until it reaches a maximum point (called the *positive* peak). It declines in the same fashion as it rose until it returns to the base line. It then "crosses" the base line and produces the same pattern below the base line as it did above it.

When the wave reaches its peak value *below* the base line (known as the *negative* peak, which is the same value reached above the base line), it then declines to the base line, crosses it, and the pattern repeats. When a wave travels in this fashion above and below its base line and returns to its starting point, it is said to have completed a *cycle*. Mathematically, a sine wave is described by the equation

$$\text{sine wave} = A \sin 2\pi ft$$

where A is the maximum peak value, or *amplitude*, of the wave, f is the number of cycles per second, and t is the time at which we want to know the value of the wave.

Sine waves are important. One reason is that all waves—even the chaotic, "sloppy" waves that lap up on the beach—are combinations of sine waves. Another reason is that sine waves are useful. The electric power coming from your wall outlet is in the form of sine waves.

When we describe waves, there are several different terms used for their various characteristics. Amplitude, as we've mentioned, is the maximum peak the wave reaches above its base line, or intensity. Another measure is the velocity of propagation, which is how fast the wave travels through a vacuum or a medium such as air or water. The velocity of propagation varies with the medium the wave travels through, with denser media slowing the wave down more. For example, a light wave travels about 300,000,000 meters per second (186,200 miles per second) in a vacuum but only about 75 percent of that speed through water.

Two interrelated ways of describing a wave are *frequency* and *wavelength*. The frequency of a wave is the number of

WAVES, WAVES, EVERYWHERE.

cycles it goes through in a specified period of time, usually one second. The wavelength is the distance between two identical points on two successive wave cycles, such as from one positive peak to the next positive peak. If you think about it, you'll realize that the higher the frequency of a wave, the shorter the distance between the same points on succeeding cycles since there are more of them in the same unit of time. The relationship between frequency and wavelength is an inverse one. The higher the frequency of a wave, the shorter its wavelength; the lower the frequency of a wave, the longer its wavelength.

The frequency of a wave is measured in *hertz* (Hz), which is equal to one complete cycle per second. The hertz honors Heinrich Hertz (1857-1894), the German scientist who first discovered radio waves. The hertz is too small for many purposes, so you will often see frequencies expressed in *kilohertz* (kHz), which is equal to 1,000 Hz, and *Megahertz* (MHz), which is equal to 1,000,000 Hz. There's even a *gigahertz* (GHz), which is equal to 1,000 MHz. Frequencies in the MHz, GHz, and even higher ranges are restricted to electromagnetic waves such as radio and light. The sound waves we hear are usually between 30 Hz to 20 kHz, although the exact range that can be heard varies with individuals.

Reflection, Refraction, and Diffraction

Wave *propagation* refers to how a wave travels from one point to another. In many cases, understanding how a wave propagates means you have to understand the roles *reflection*, *refraction*, and *diffraction* play in the process. These three phenomena are shown in Figure 2.

Reflection occurs when a wave strikes a denser reflective medium, as when a light wave strikes a glass mirror or a sound wave strikes a distant wall and returns as an echo. The wave that strikes the reflective medium is called the *incident* wave. The incident wave strikes the "interface" between the less and more dense media at a certain angle of incidence. The wave is reflected at an angle known as the *angle of reflection*. The *angle of incidence* and the angle of reflection are exactly the same. Because these angles are equal, we can often trace a reflected wave back to its origin. This is the principle behind radar which uses radio waves) and sonar (which uses sound waves).

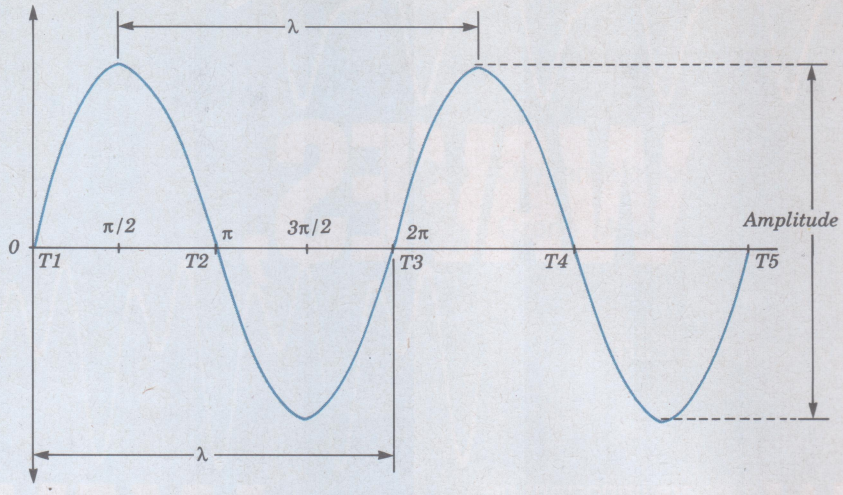


Figure 1. Sine waveform showing phase, time, and amplitude relationships.

Refraction takes place when an incident wave enters a region of different density and undergoes both velocity and directional changes. The amount and direction of the change are determined by the ratio of the densities between the two media. If the two media are highly dissimilar (such as when a layer of dry, cool air meets a layer of warm, moist air), then the bending of the wave is great. It is possible for refraction and reflection to occur in the same system.

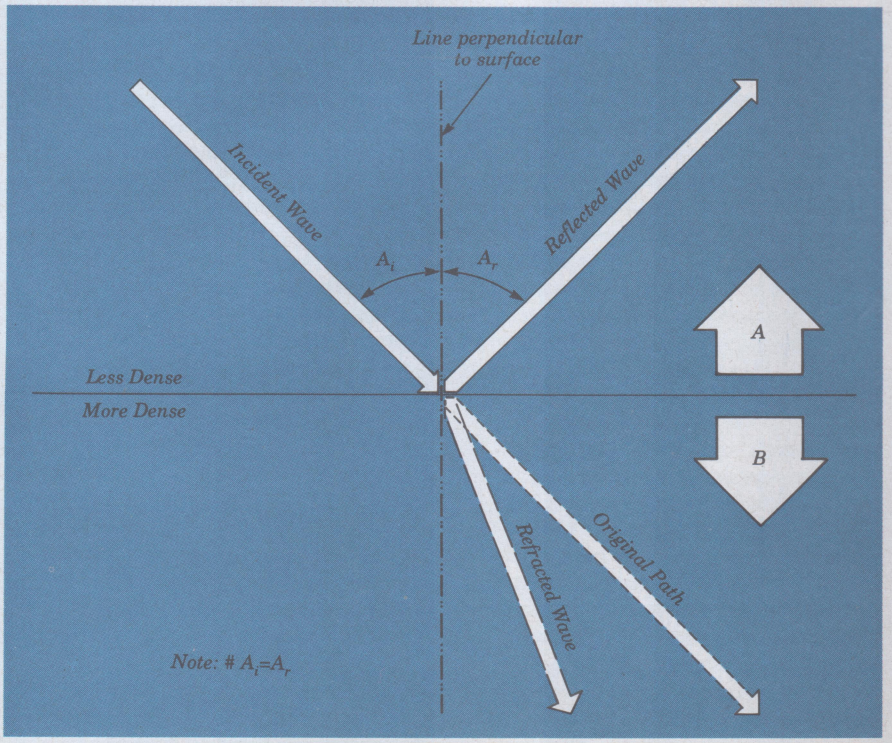


Figure 2. a) Ordinary specular (non-diffuse) reflection and refraction phenomena; b) diffraction phenomena.

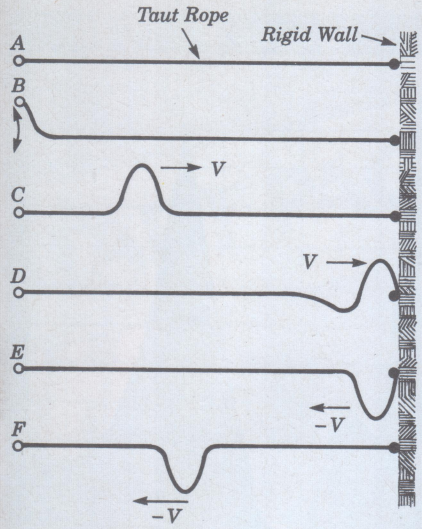


Figure 3. "Rope analogy" for standing waves.

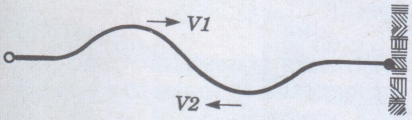


Figure 4. When an incoming incidence wave hits a reflected wave, they interfere with each other, producing an amplitude that is the algebraic sum of the two.

Standing Waves

The term "standing waves" doesn't refer to waves that literally "stand still" in space or a medium, although it seems as if they do. Standing waves are found in systems where waves can reflect and there is a "recombination" of incident and reflected waves. The best way to visualize standing waves is by the "rope analogy" experiment.

All you need to perform this experiment is a rope or similar object (long belt or strap, etc.) and a wall or tree to tie it to. The rope should be capable of being pulled taut, and the wall or tree should be as rigid as possible.

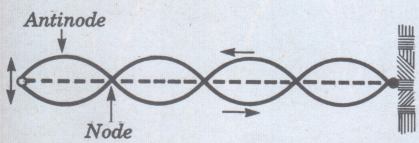


Figure 5. When the end of the rope in Figure 4 continuously oscillates, the interfering incident and reflected waves set up a standing wave pattern.

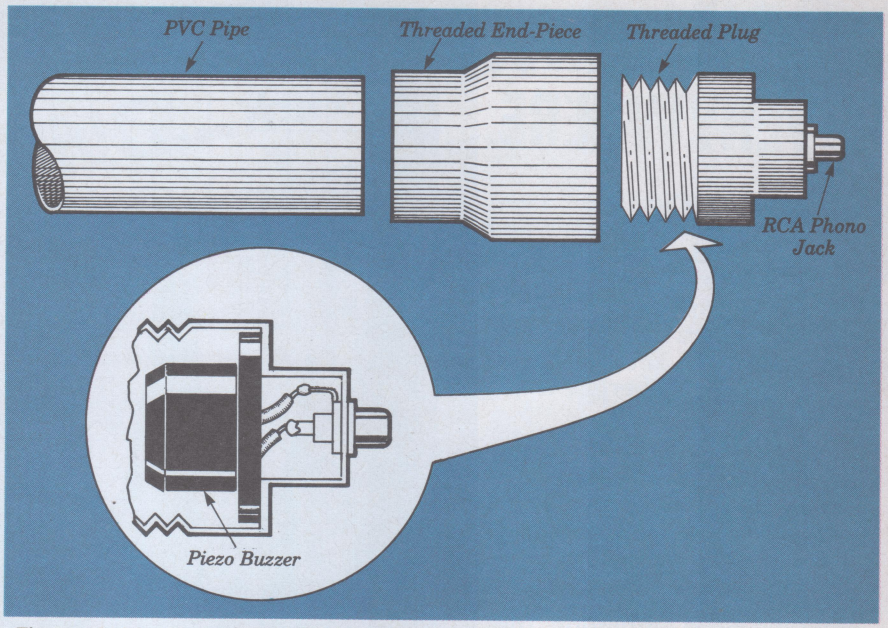


Figure 6. How to assemble the transmitter end of the sound pipe.

After tying the rope to the support, take its free end and give it a vertical displacement (in other words, shake it!). The "pulse" produced by shaking the rope will propagate through the medium (*i.e.*, the rope) down to the tree or wall. When the wave hits the wall or tree, it will be reflected and will travel back down the rope toward the free end where it originated. Figure 3 illustrates these movements of a wave along a rope.

If a second wave is sent down the rope before the first one dies out, there will be two waves on the rope at the same time. When the two waves meet, as shown in Figure 4, the result will be the algebraic sum of the two. If both waves are on the positive halves of their cycles, the resulting wave will have a greater amplitude than either of the waves. If one wave is positive while the other is negative, the result will be a wave whose amplitude is less than the largest amplitude of the two waves.

Now suppose you keep shaking the free end of the rope in a regular, steady fashion and send a "train" of waves down the line. As the waves propagating down the rope meet and interfere with waves being reflected back, the result will be a pattern in the rope where it appears as if the waves are standing still. This phenomenon is illustrated in Figure 5. Actually, waves are still being propagated in both directions along the rope, but the interference between the incident (or "forward") and reflected (or "reverse" waves creates the standing waves on the rope.

Building a Sound Pipe

When most of us think of waves, we don't think of those

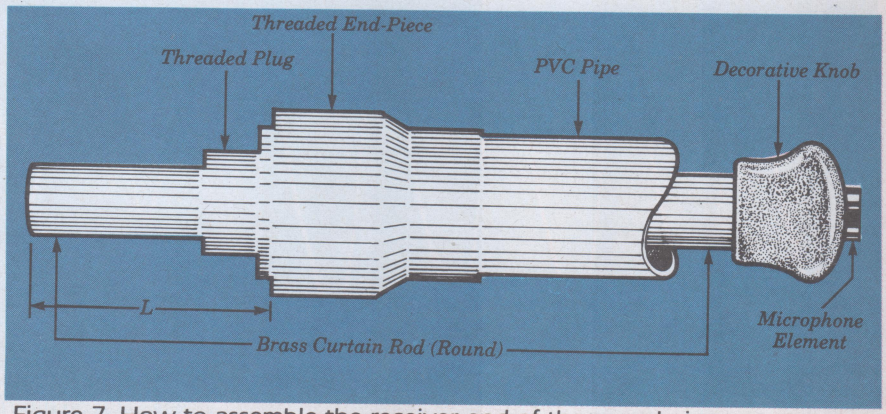


Figure 7. How to assemble the receiver end of the sound pipe.

WAVES, WAVES, EVERYWHERE.

produced by shaking a rope. Instead, we think of something like the sound waves we make whenever we talk. Standing waves are found in sound waves as well, and it's easy to construct a device, known as a *sound pipe*, to experiment with them.

The idea behind our sound pipe experiment is to inject a sound wave—manifested as air pressure variations—into the pipe at one end and then detect the maxima and minima indicating the rise and fall of the standing wave amplitude. The sound pipe is a 1.22-meter (4-foot) length of PVC pipe with a sound source at one end and a microphone at the other. In the unit I built, a piezoelectric buzzer served as the sound source. The signal from the output of the microphone is very weak and needs amplification, so it is fed to an audio amplifier circuit.

For my sound source, I selected a piezoelectric buzzer available at a Radio Shack store. While not adjustable like other kinds of sound sources, it has the advantage of being self-contained and inexpensive. Its nominal operating frequency is 3,500 Hz (mine actually operated around 3,250 Hz) and can be powered from six to 20 volts DC.

Figure 6 shows the construction details of the transmitter end of the sound pipe. A threaded end-piece is glued onto one end of the PVC pipe, and the piezoelectric buzzer is mounted in a matching threaded plug.

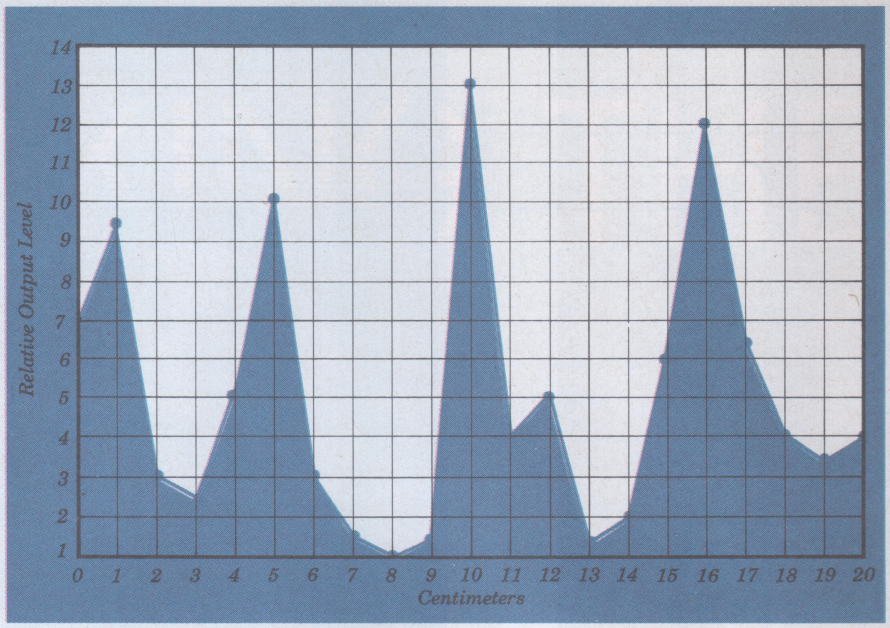


Figure 8. Experimental results obtained by the author. Data taken at one centimeter intervals for about 20 centimeters.

The threaded plug will have to be modified to accept the piezobuzzer. One end of the plug is square, and I drilled a small hole into this end to accept an RCA phono jack. As an alternative, you could just fit a rubber grommet into the hole and bring in the power wires for the piezobuzzer directly. If you do use the phono plug, don't let it come into contact with metal or other conductors to prevent the battery from being drained.

I used a pair of #4-40 machine screws and hex nuts to fasten the buzzer to the inside of the plug. Some shaving of the PVC plug may be necessary to make the buzzer screws fit. I used an ordinary file to make the screws fit.

As shown in Figure 7, the receiver end of the sound pipe is fitted with another threaded end-piece and threaded plug. In this case, however, the plug is drilled out to make a hole capable of accommodating a 1.25-centimeters (1/2-inch) aluminum, copper, or brass tube. (I was able to salvage a usable piece of brass tubing from a curtain rod.) One end of the rod remains outside of the PVC pipe while the other end is inside the pipe. This inside end is fitted with either an end cap or, in the case of my curtain rod, a decorative knob.

I glued the microphone into a hole cut for that purpose in the decorative cap. I made a hole

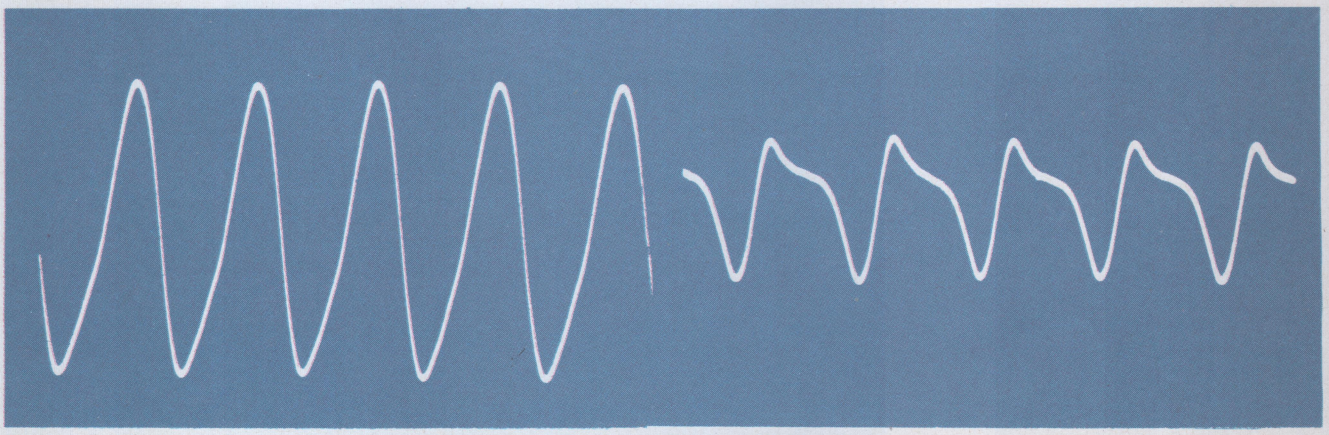


Figure 9. Oscilloscope photograph of the sine wave generated by the piezobuzzer.

Figure 10. Oscilloscope photograph that shows interference of sound waves in the sound pipe.

CONSTRUCTING THE OUTPUT INDICATOR CIRCUIT

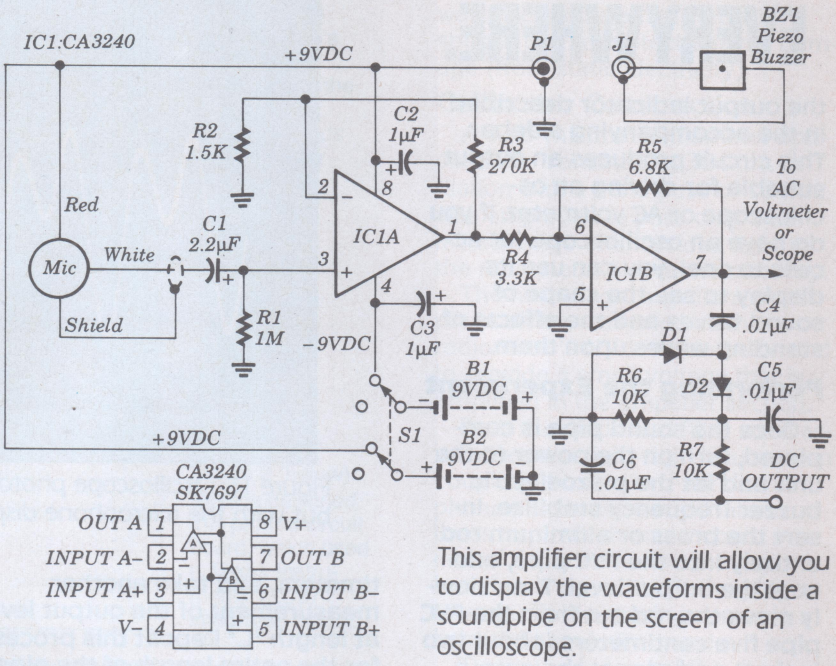
If you know how to use an oscilloscope, you're aware of what a terrific analytical tool a displayed waveform can be. The output indicator circuit described here will let you display the waveforms inside the sound pipe on an oscilloscope.

The circuit is basically an audio amplifier using on low cost operational amplifiers (op amps). The electret condenser microphone is powered directly from the power supply (V+) that is also used for the operational amplifiers. This same power supply also provides the power for the piezobuzzer through plug P1 and jack J1. The other power supply (V−) is used only for the op amp. Both V− and V+ power supplies are ordinary 9-volt transistor radio batteries.

The op amp, IC1, is a dual device that contains two amplifier sections that are independent except for the V- and V+ DC power supply terminals (pins 4 and 8, respectively). You can use either the CA3240 or 1458 devices. The 1458 devices are inexpensive and easy to obtain, but they will not work well at higher frequencies. The CA3240 is more expensive and difficult to locate (I had to order mine by mail), but it offers superior performance.

The input amplifier section (IC1A) is an AC-coupled non-inverting follower. The gain is one more than the ratio of the two feedback resistors (R2 and R3) or, in this case, the gain is nominally 181. An input resistor, R1, is used to prevent the input capacitor from being charged by bias currents from IC1A.

Note that the power pins (4 and 8) of the operational amplifier are bypassed to ground with 1-µf capacitors. These capacitors are needed to keep the op amp stable and prevent self-oscillation. The capacitors must be mounted as close to the body of the op amp as practical. It may be possible to delete these capacitors if a 1458 device is used, but they are absolutely required if the CA3240 is used.



This amplifier circuit will allow you to display the waveforms inside a soundpipe on the screen of an oscilloscope.

The output signal at pin 1 from IC1A is about 181 times higher than the signal applied to the input (pin 3). This level may be sufficient for many situations, but in this case I found that a little more amplification is needed. This amplification is provided by the second stage, IC1B. This circuit is connected as an inverting follower amplifier, and with the resistor values (R4 and R5) shown the gain is about 2. The phase of the output signal at pin 7 is the opposite of the input signal, but that is not a problem in this application.

The output signal from IC1B can be applied to an audio or AC voltmeter as well as an oscilloscope. If you don't have such nice instruments, add components C4, D1, D2, R6, C5, C6, and R7 to the output as shown. They form a voltage multiplier rectifier circuit that will produce a pulsating DC voltage output that can be measured with a conventional DC voltmeter or multitester.

I built my amplifier circuit on a piece of copper-clad "perf board" such as that available from Radio Shack. I selected a board that has a universal integrated circuit copper pattern on one side to simplify soldering and construction.

that provided a snug fit for the microphone and secured the microphone in place with rubber cement. With this arrangement, the microphone can be moved inside the PVC tube so that it is closer or further away from the sound source.

The wires leading to and from the microphone are brought out through the inside of the rod, which is why hollow tubing is used instead of a solid dowel. You'll notice in Figure 7 that there is a length labeled "L." This will be used later when we make some measurements with the sound pipe.

The signal from the microphone is very weak and needs amplification. One way to do this is to use a tape recorder or audio amplifier that's already equipped with an electret or condenser type microphone and has some sort of external microphone jack or input. If you use a tape recorder, be sure it has a monitor function that allows you to hear the sound being recorded. Not all recorders have this feature. Look for a "Monitor On/Off" or similar switch on the recorder.

I used an ordinary 9-volt transistor-radio battery to supply power to the microphone. If you use the Radio Shack microphone specified in the Parts List, connect the battery between the red power wire and the conductive shield. The shield and the white wire (inside the shield) are used to carry the signal to the audio amplifier.

Some sort of output indicator device is also needed. If a tape recorder or audio amplifier is used, then the loudspeaker in such a device is suitable. The amplitude of the sound coming from the speaker indicates the relative amplitude of the standing wave. This trick works even better if the recorder is equipped with a level meter, which will let you make numerical records of the wave amplitude.

Another approach is to build

the output indicator described in the accompanying sidebar. This circuit produces an output suitable for driving an oscilloscope or AC voltmeter. If you do have an oscilloscope (or access to one), you can use its display to see the shape of sound waves and the effects of standing waves upon them.

Performing the Experiment

Once the sound pipe is completed, turn on the power to the unit and let the piezoelectric buzzer frequency stabilize. Insert the brass or aluminum rod entirely into the PVC pipe, and note the output level. Then slowly move the rod out from the PVC pipe five centimeters (about two inches) and repeat the output level measurement. The distance that you move the rod out from the PVC pipe is the distance "L" indicated in Figure 5, the illustration for the microphone end of the PVC pipe. Move the pipe out another five centimeters, and take another measurement of the output level at length "L." Repeat this process for the entire length of the pipe.

You should note a peak in the wave approximately every five centimeters as "L" gets larger, and these peaks represent half-wave points on the standing wave. Given that sound propagates at about 33,150 centimeters per second (1,088 feet per second), these represent a frequency of approximately 3,315 Hz. The measured frequency of 3,250 Hz compares well ("within experimental error limits," as professional scientists say) with this result.

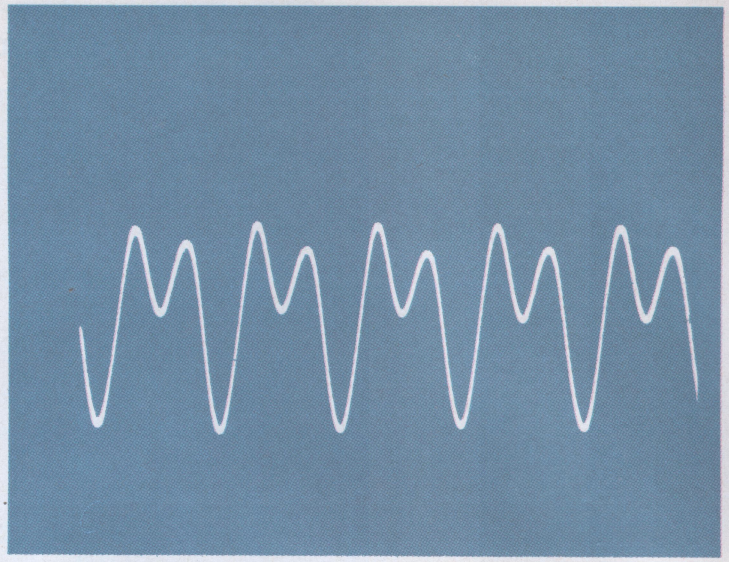


Figure 11. Oscilloscope photograph similar to the one in Figure 9 but with the microphone displaced a few centimeters.

Figure 8 shows the results I obtained with the sound pipe I made. You can make the result come out closer to the theoretically predicted value by making very certain of the length measurements, making measurements along the entire length of the rod (instead of over only 20 centimeters as I did), and repeating the experiment several times. You can then take the mean (average) of the results.

If you connect an oscilloscope to the output indicator circuit described in the sidebar, you'll probably achieve results similar to those shown in the accompanying oscilloscope photographs. The photograph in Figure 9 shows the "pure" sine wave output of the piezobuzzer with the microphone placed all the way inside the PVC pipe near the front of the sound source.

(Continued on page 126)

PARTS LIST

Integrated Circuit: IC1—CA3240 operational amplifier (available from Digi-Key)

Resistors
(Either 1/8 or 1/4 watt types may be used.)
R1—1,000,000-ohm (1 megohm)
R2—1500-ohm (1.5 kilohm, abbreviated 1.5K)
R3—270K
R4—3.3K
R5—6.8K
R6, R7—10K

Capacitors:
C1—2.2μF, tantalum
C2, C3—1μF tantalum
C4, C5, C6—0.01μF ceramic disc

Diodes:
D1, D2—1N4001 (Radio Shack 276-1101 or equivalent)

Other Parts:
BZ1—Piezoelectric buzzer (Radio Shack 273-075 or equivalent)
Mic—Electret microphone (Radio Shack 270-092B or equivalent)
J1—1/8-inch jack (Radio Shack 274-251 or equivalent)
P1—1/8-inch plug (Radio Shack 274-286 or equivalent)
S1—Double-pole, single-throw (DPST) toggle switch

Miscellaneous: Enclosure for completed circuit (select according to size of circuit board used), insulated hookup wire, bolts, nuts, washers, and other hardware, two 9-volt battery connectors (Radio Shack 270-325 or equivalent), two 9-volt battery holders (Radio Shack 270-326 or equivalent)

Parts Sources:
All Electronics, P. O. Box 567, Van Nuys, California 91408
Digi-Key Electronics, 701 Brooks Avenue South, P. O. Box 677, Thief River Falls, Minnesota 56701-0677
Radio Shack stores are located throughout the North American continent and overseas. Check the white pages of your local telephone book.

ABOUT THE AUTHOR

Joseph J. Carr is a prolific writer of articles and books on many aspects of electronics. His articles regularly appear in *Popular Electronics* and *Radio-Electronics* magazines.

A Traveling Science Laboratory

The Physics of Gears, Wheels and Wind

Story and Photos by Trudy E. Bell

Summary

Experience is the best teacher, even when it comes to learning about physics. Few machines can demonstrate the laws of physics in action as well as the bicycle. Come along with cyclist Trudy E. Bell on a ride through the world of bicycle science. You'll arrive with a better appreciation for the efficiency of two-wheel travel — and physics.

When I was 17, the laws of physics seemed abstract to me, even though I **allegedly** was a college freshman physics major. Had I been the avid bicyclist then that I am now, physics would have been much easier to relate to.

Cyclists today use knowledge of both physics and physiology to improve performance and endurance. In fact, you can use a bicycle to demonstrate many fundamental principles, ranging from simple machines through the laws of thermodynamics. At the very least, it'll give your mind something to do when you're bucking a stiff headwind or grinding up a steep hill.



Author Trudy Bell shows the best way to carry a load on your bike.

Mechanics 101

The wonderful thing about a bike is that, unlike city hall, all its guts and workings are exposed to the public eye. And it's all straight textbook physics.

Any bicycle is a compound machine — that is, a combination of simple machines. In fact, a derailleur bike — that is, one with five or more "speeds" or gear ratios — includes these simple machines: lever, wheel and axle, pulley, screw and wedge. Only the inclined plane is missing. (Wedge? Yes, wedge. I'll let you puzzle over where for just a bit.)

If you remember from your high school physics class, the simple machines, singly or in combination, can do five highly useful things:

Transform energy from one type to another — A bicycle converts your rotary muscular energy into forward motion while pedaling, or forward motion into heat while braking.

Transfer energy from one place to another — The chain transfers the motion from the pedals back to the rear wheel.

Divide or multiply force — Low gears divide force when your bike climbs hills, so the wheels may be rotating more slowly than your feet pushing the pedals.

Multiply speed — High gears increase speed when you race on the flat, so the wheels are rotating up to four times faster than your feet are pushing the pedals.

And, change the direction of force — Gear levers and cables change the direction of force, by moving the derailleur left and right when you press the gear lever up and down.

The wheel and axle is the most obvious machine, as it is the reason the vehicle is called a bi-cycle.

The lever is the next easiest to find. You stop a derailleur bike by pulling on the brake levers with your hands. And how do you shift? By moving the gear levers, which pull on cables. The cables move either the front or rear derailleur against its hinged fulcrum to shift the chain left or right to another front chainwheel or rear cog. While pedaling, you can also lever yourself against the bike by pulling up on the handlebars with your arms to increase the amount of force your feet exert on the pedals to greater than that of your weight.

In addition, when you fix a flat, you pry the tire off the rim using a set of tire levers. Here, the fulcrum is the bend in the tire lever braced against the edge of the rim. The lever is also central in a static application: holding the wheel into the front and rear forks with the quick-release skewer.

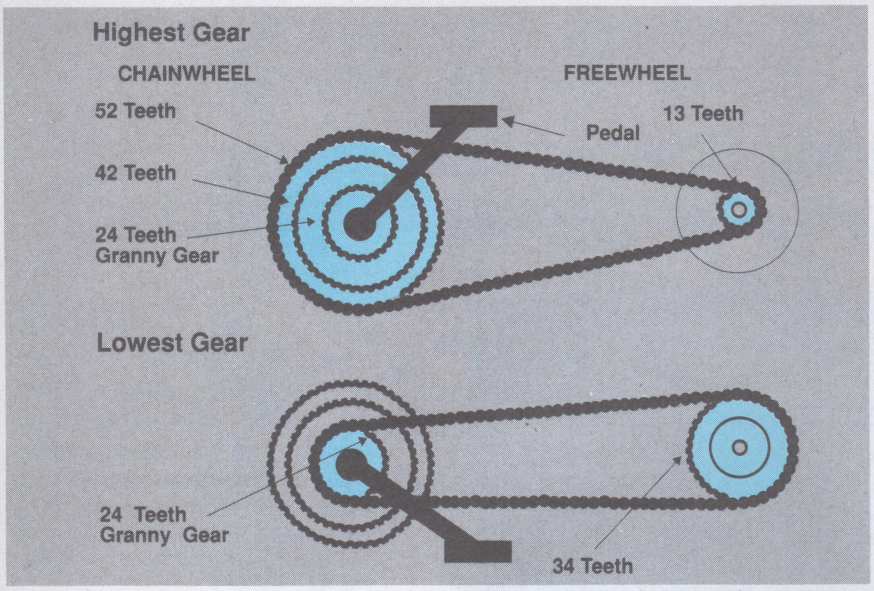


Figure 1: Here is a somewhat extreme example of the triple crank on a touring bike, optimized for hillclimbing. The highest gear, which I almost never used, gave a ratio of 52 teeth in the front to 13 teeth in the rear: each turn of the pedals, then, rotated the wheels 4 times – excellent for speeding down hills or before a tailwind. The lowest alpine or "granny" gear, gave a ratio of only 24 teeth in the front to 34 teeth in the rear: each turn of the pedals, then, rotated the wheels only 2/3 of their circumference. Count the teeth on your own gears to calculate your ratio.

WARNING: The road tests described here, and all cycling, have an element of hazard. You should not attempt them without wearing a helmet that has passed either the ANSI (American National Standards Institute) test, or better yet, the Snell test for impact. Observe all traffic safety laws. Children should be supervised by an adult.

Screws are also self-evident, although not in the action of the bike. They simply hold a lot of it together or act as adjustable stops for the derailleurs.

(But where's the wedge?)

The whole bike is propelled by a modified pulley. Yes, I know a pulley is usually a grooved wheel over which you can throw a rope and raise a load. A system of several pulleys can make the job even easier.

On a bike, the pulleys are given teeth instead of a groove, and are turned into the chainrings (the front gears) pulling the chain around by the force of your feet on the pedals. The exact ratio of teeth on a chainwheel and teeth on a particular rear cog of the freewheel can multiply the force of your legs to speed you down a hill or in a race. Or it can divide that force, which slows you but eases the work of each rotation of the pedal in carrying yourself uphill. (Figure 1.)

There's also a more conventional pulley changing the direction of force: the humble and usually gunk-covered, hard plastic jockey wheel at the end of the derailleur. This mechanism redirects the chain forward and up over the freewheel.

Have you figured out where the wedge is?

Actually, in many bikes there are two wedges — neither doing anything dynamic, but acting in the good, ancient wine-barrel-bung tradition of holding something tightly inside an opening. Unscrew the Allen bolt holding the handlebar stem in the fork's steerer tube and pull out the stem and handlebars.

From the bottom of the stem dangle two wedges, each one-half a cylinder on the outside with the inclined-plane surfaces pressing against each other. (See Figure 2.) Instead of being driven together and wedged into the headset by hammer blows, the Allen bolt (acting as both a screw and lever) pulls one up closer to the other, making an effective expansion joint.

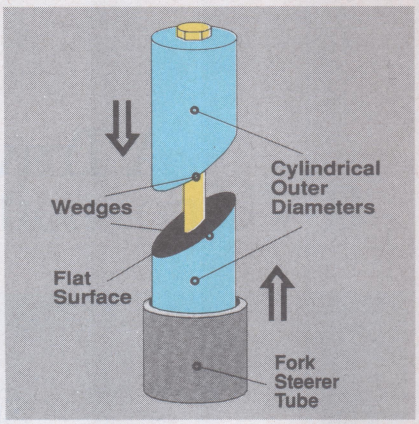


Figure 2: Two wedges hide in many bicycle headsets. The diagonal division is two inclined faces of the wedges pressed together.

Keep these wedges well-greased, or you won't be able to loosen them and adjust the height of your handlebars.

The Rolling Wheel

Now that you're looking at your bike as a rolling physics lab, let's take it outdoors to try a few experiments.

You'll need a long, flat paved driveway or parking lot that you can block off after hours, and a nearby paved hill of considerable length and steepness. A hose, an inked stamp pad, some graph paper, a large piece of plywood and some chalk would also be helpful. If you want to be really quantitative and perfectionist about this whole project, you might also want a tape measure, stopwatch, thermometer and the like.

For best results, get a friend with a different kind of bike. The comparisons of a fat-tire mountain bike with a thin-tire road bike are ideal. Bicycles built for two (tandems) or bicycles with seats that stretch riders' legs out in front of them (these are called recumbents) would be fascinating as well. In fact, write to me: I'd love to know how they compare with standard bikes.

A bike, even without a rider, is quite stable at high speeds but is unstable at low speeds (accounting for why beginners find its mastery so tough). See for yourself.

On the level, point a riderless bike straight ahead and give it a shove forward, counting "1001,



A riderless bicycle can travel a fair distance if given a strong shove, owing to the flywheel action of its rotating wheels. To avoid damaging the bike, have an assistant catch it, as my upstairs neighbor Alan Arbel did for me.

1002, 1003 . . ." (or clicking the stopwatch) to mark time when you let go. The riderless bike will travel a certain distance until it slows down and begins to fall. Have a friend catch the bike **before** it hits the ground to avoid damaging the bike. Try this with weaker and stronger shoves, and with the two different designs of bikes. You will find that the stronger shove to the bike with the heavier wheels gives the longest stable travel.

The principal reason for a riderless bike's stability, particularly at higher speeds, is the flywheel action of its rotating wheels. (The geometry of the bicycle's frame also plays a role, accounting for why a riderless mountain bike may travel farther.)

The rate of each wheel's rotation — that is, the angle through which the wheel turns, divided by the time required for that turning — is the *angular velocity*. The faster the rotation, the faster the angular velocity. Now, angular velocity includes not only the rate of rotation, but also the direction of rotation. Once spinning, the wheel "wants" to continue spinning in the same plane and is not easily turned. Thus angular velocity is represented by a vector through the axis of rotation.

By convention, if the fingers of your right hand curl around the axis in the direction of the wheel's rotation, the extended thumb points along the direction of the angular velocity vector. And the faster the rotation, the longer this vector.

The wheel's mass also comes into play. A heavy mountain-bike wheel rotating at a certain number of revolutions per minute (rpm) requires more effort to stop than a superlight racing wheel rotating at the same rpm, by an amount proportional to their respective masses.

The Spinning Wheel

Test the angular momentum vector for yourself. Remove the front wheel from the bike. Try this with a racing bike wheel first, then a mountain bike wheel.

Hold the front wheel horizontally in front of you with the axle vertical. Grasp each end of the axle — your right arm stretched out above the wheel, your left arm below. Mark one of the spokes with tape.

Have your friend spin the wheel clockwise, up to a certain number of revolutions per minute (count the revolutions by watching the tape). Now, using the right-hand rule, you can determine that for a clockwise spinning wheel, the angular momentum vector is pointing down.

Now, try to flip the wheel over so your right arm will be on the underside as shown in these photos. Hold on tight and **be careful.** Amazing! The wheel resists and may even throw you off balance.

One classic physics experiment is to perform this maneuver while sitting on a stool that freely rotates. If the wheel is massive enough and you get it going fast enough, the wheel actually stops spinning when you flip it over.

And, **you** will start rotating clockwise on the stool! Why? Because the angular momentum vector must remain pointing downward, and so was transferred through your arms to your body. You spin more slowly, of course, because you have more mass than the wheel.

You'll find that angular momentum has indeed been conserved if you work out the equations with mass and rpms for you and the wheel.

To verify this, flip the wheel over again. You'll stop turning, and the wheel will once again be spinning in front of you. (With a heavy enough flywheel, this is a most dramatic demonstration. Some science museums, such as the Franklin Institute in Philadelphia, have a hands-on demonstration of this principle.)





And what is this product of mass and velocity? Momentum, of course. And since the wheel is rotating, this is *angular momentum*. So, the more massive the wheel at a given rpm, the greater its angular momentum vector.

This resistance of the wheel to a change of direction is the flywheel action that keeps the riderless bicycle stable and moving forward at a moderate to high speed.

But just as a top starts wobbling as it loses energy through friction, as friction slows the bike, so also the angular momentum of the wheels decrease. The vector shortens, and the wheels become less resistant to small perturbations pushing them to the side — a stone in the way or simply the unevenness of the pavement. The bike starts to wobble and eventually falls over.

Friction's the Rub

Don't curse friction, though. In some cases it is undesirable — say, in a brake pad rubbing against a rim or in an inadequately lubricated chain. In other cases it is vital to the control of a bike.

Friction is a force that opposes motion, of one material either against another or through another. It's immaterial whether it is caused by microscopic-scale irregularities in their surfaces, adhesion of one material to another, or electrical forces similar to those that hold atoms and molecules together.

One of the reasons racing-bike tires can be narrower than 2.5 centimeters (1 inch) wide is to minimize the amount of rubber that contacts the road. This minimizes rolling resistance, the friction between the rubber and the road. Less friction means the cyclist works less to gain a certain speed, and can attain higher speeds — or travel for longer distances — for the energy put out. But zero friction would also be no good, as any cyclist whose tires have slid out from under the bike on ice can attest.

Any tire, no matter its width, must support the weight of the bike and rider. For narrow tires, that means the air pressure in the tires must be high: 110 to 115 pounds per square inch (psi). (Around the world, bicyclists specify tire pressure in psi, and so shall I.) Such racing tires also have very fine tread, or even no tread at all on special "bald" tires.



The Univega SportTour bike (left) has thinner tires, less knobby tread, and less leveraged cantilever brakes with smaller pads than the Montague BiFrame mountain bike (right).

Mountain bikers, on the other hand, don't particularly care about breaking speed records. They want to reliably plow through sand and gravel and bounce over branches and rocks. The rubber must solidly grip the shifting and uneven surfaces, so everything is done to maximize the tire's surface area. The tires are not only fat — 3.8 to 6.4 centimeters (1.5 to 2.5 inches) — but also made with knobby tread, and filled to far less air pressure.

In fact, the recommended air pressure embossed on the side of a mountain-bike tire is likely to specify two pressures: The label on the 1.5-inch tires of my Montague BiFrame reads "65 psi road/40 psi off-road."

The lower off-road pressure is to make the tire squishy and malleable — firm enough to prevent the rider from bouncing directly on the expensive metal rim, but soft enough to wrap around obstacles for good traction. The lower pressure also absorbs a lot of shock rather than transmitting it through the frame to the rider.

In general, the fatter the tire, the lower the pressure required to support bike and rider, because the weight is spread over a wider area. And pressure, of course, is weight (force) per unit area.

It's easy to get a qualitative feel for tire contact area and rolling resistance. Tape graph paper onto a sheet of plywood and lay it on flat pavement. Take the racing bike, rest its front tire on an inked stamp pad, and then carefully set the inked tire near one edge of the graph paper to make a mark while you rest your whole weight momentarily on the seat.

The resultant spot shows you the contact area of the thin tire on the pavement when you are riding that bike. Do the same with the mountain bike, at both the higher and lower recommended pressures. If you've inked enough of the tire so that all the parts that contact the ground have been covered, the mountain bike spots will be larger, with the lower-pressure spot the largest of all.

If you're into the math, it's straightforward to verify the physics. Measure the size of each spot to calculate its area, then double it (to account for the support of the rear tire as well). Weigh yourself and the bike, and divide that weight by the calculated area. The answer in each case should be the actual air pressure in the tire.

A dynamic — and more fun — way to show the same phenomenon is to spray a part of the pavement with the hose, then ride through the wet area on both bikes, comparing the width of the wet tire prints.

To qualitatively show how rolling resistance makes a difference in on-road performance, take the bikes to the top of a paved hill and from a standing start coast down to the base, timing the descent and maximum speed (easy to record on those battery-operated bicycle computers). Care to lay odds?

My money is that the racing bike coasts fastest, then the mountain bike at the higher pressure, with the mountain bike at lower pressure bringing up the rear. That's why riding a bike with under-inflated tires can be such hard work. (Since the pneumatic tires are also the bike's shock absorbers, riding under-inflated tires is

also a fast way to ruin expensive rims.)

To verify how these differences translate into off-road handling and control, take the bikes on a gravel road. Here the mountain bike with the lower pressure gives the surest ride, while the racing bike will be a challenge to keep upright and may even throw you. (The mountain bike at higher pressure is most useful for commuting over potholes or for long-distance touring over roads in all conditions.)

Stop Action

All bikes depend on friction for one vital function: stopping. On most derailleur bikes, most brakes — no matter their design — stop your forward motion by rubber pads that grip the metal rims of the front and rear wheels. Your forward energy is converted to heat by friction, which is dissipated by the rim. Essentially, the rim becomes a radiator or heat sink.

The amount of heat is no little matter, either, as you can easily test. Take both bikes and your friend back to the top of the paved hill. Then, from a side-by-side standing start, coast on the bikes as fast as they will go, trying to brake only near the end.

After you stop, touch the front rim of each bike. Actually, after a truly steep hill, you may not even be able to comfortably touch the narrow rim of the racing bike. In fact, for heavy riders or tandems racing down long hills at high speed, the rims get so hot they have been known to cause the brakes to fade and smell, patches to sizzle off the inner tube, and the glue holding sew-up tires onto the rims to melt. The wider mountain bike rim will be noticeably cooler, for the obvious reason: greater radiating surface to dissipate the same amount of heat.

By the way, this heat of friction is the reason for the technique of feathering or pumping the brakes as you coast down a hill. By successively applying and releasing the brakes instead of gripping them steadily, the rims have a chance to dissipate the heat and ensure more reliable braking.

(One time when I was coasting down steep Reddish Knob in Virginia, I had to stop occasionally to let the rims cool — and to massage the charley horse out of my forearms! And a bike mechanic informed me that one local amusement was to plummet down at night on a one-speed bike. The coaster-brake hub would get so hot it would glow dull red! Not a sport I recommend.)

Now, if you want a dramatic demonstration of how important

The Physics of Safety

One uncommonly warm spring morning in March 1987, I was accelerating down Palisades Avenue in Englewood, New Jersey, when I noticed gravel on the road.

I moved my right hand down from the handlebars onto the brake, but my camera-laden handlebar bag began to shimmy before I could get my left hand down as well. The rear wheel locked, the bike slid out from under me to the right, throwing me left into the roadway. I hit the pavement at some 25 kmph (about 15 mph) in a rolling fall, ending with my head.

The moment my head cracked the asphalt, I knew I was not hurt. I also knew it was because of the protection of my Bell V-1 Pro helmet. The next day my neck muscles were so sore they could not support my head bent over a desk. But no matter — the grooves from the gravel were in the hard outer shell of my helmet, not my skull.

That instant, I got religion. I now show that grooved helmet to all my bicycle-touring students to drive home the necessity of head protection. For a cyclist, the question is not **if** you'll fall, but **when.**

Each year in the United States alone, an estimated half-million cyclists are injured, and more than a thousand are killed. In 80% of the cases, head injury is the principal or contributing cause of death. In other cases, it caused permanent paralysis or other brain damage. Yet only about 20% of adults and 5% of children wear helmets.

One major misconception among cyclists is that their lower speeds put them at less risk than, say, motorcyclists. But studies have shown that injuries occur not because of horizontal speed, but because of the vertical distance your head travels to hit the pavement.

Even from a standstill, the average cyclist's head — which is 162 cm (5 feet, 5/16 inches) off the ground — will hit the ground at 20 km (12.6 miles) per hour,

Even from a standstill, the average cyclist's head . . . will hit the ground at 20 km (12.6 miles) per hour, which is the threshold of irreversible injury to the brain.

which is the threshold of irreversible injury to the brain, according to studies by the University of Southern California's Head Protection Research Laboratory.

Even an unprotected fall of only 110 cm (3 feet, 10 inches) — the height of a child on a bike or an adult on a recumbent — can cause fatal brain damage.

A bicycle helmet is generally lined with expanded polystyrene bead, a denser version of the material of a Styrofoam cup. Upon impact, the polystyrene is crushed, absorbing the force — to the point that, even with a head-first landing on pavement, it is rare for a helmeted cyclist to be killed.

Serious cycling helmets have passed one or both of two sets of standardized tests: one by the American National Standards Institute (ANSI) and the other by the Snell Memorial Foundation.

Both tests evaluate impact protection by subjecting helmets to different conditions (such as cold, heat and rain) and then dropping them onto flat and hemispherical anvils while measuring g-forces from an instrumented headform weighing 5 kilograms. Both tests specify that the impact should not exceed 300 g's, where the threshold for permanent head injury is 400 to 600 g's.

My trusty Bell V-1 Pro, which protected my own head five years ago, passed both the ANSI and the Snell tests.

"Ah, but I like the feeling of the wind through my hair."

"Helmets are too hot."

"I can put out my hands in time to break my fall."

"Look, I already spent $400 on this bike, you want me to spend another $50 on a helmet? If I outfit my whole family, that'll be another $200 in helmets alone."Today's soft-shell helmets are far lighter and breezier than the heavier models of the early 1980s, although I personally still prefer a hard shell for maximum protection.

Most important, a $50 helmet is cheaper than an emergency-room charge.

Or lifelong medical care.

Or a funeral.

brake-rim friction is to stopping, return to the flat parking lot. Chalk a mark about halfway across. Then get on one of the bikes at the far end, pedal until you're going at a moderate speed — say, 15 kilometers (about 10 miles) per hour, and then when your front wheel crosses the chalk mark, brake as hard as you safely can.

Make another mark where the front wheel actually stopped. Now, hose down the course with water, creating enough puddles to thoroughly wet the rims. Go through the braking exercise again, but easy does it — note how the braking distance may have doubled or more, especially for the racing bike.

Because the wind is such a dramatic factor . . . , touring cyclists try to choose their routes based not only on terrain and traffic but also on prevailing winds.

The cantilever brakes of the mountain bike, with their wider pads and leveraged grip, stop their steed faster when wet than standard sidepull or centerpull brakes.

By measuring the area of the pads and the stopping distance and calculating your momentum, you can figure out how much more leverage the brakes have.

Please don't try the following. Just consider what would happen if you poured a tiny bit of motor oil into one of those puddles and repeated the braking experiments with both bikes. Whoa! Outta control! And the braking distances might quadruple because the oil severely reduces friction between pads and rims, even on the mountain bike.

This sobering test, in addition to elucidating the role of friction, demonstrates why cyclists absolutely must slow down when riding in the rain, especially through puddles topped with an iridescent film of oil from the streets. (To clean such oil off your metal rims and brake pads, use paper towels soaked in plain old rubbing alcohol — the best, cheapest and safest frame and component cleaner around.)

A little metallurgy: Steel rims are significantly worse when wet than aluminum ones. And the old dimpled aluminum rims — which were supposed to stop shorter — were worse than smooth ones because the dimples carried water (and oil) to lubricate the pads!

"May the Wind Be at Your Back . . . "

Because the wind is such a dramatic factor in speed, work and enjoyment of bicycling, experienced touring cyclists try to choose their routes based not only on terrain and traffic but also on prevailing winds. If you live in a region with strong, windy days, you can test several effects for yourself.

Wind resistance is actually caused by two types of forces. One is perpendicular to the surface of the resisted body (felt as the pressure of the wind against your face and chest). The other, which is tangential to the surface, is known as "skin friction." For an unstreamlined form, such as a cyclist, the pressure effect is the greater of the two, with much of the wind-pressure energy dispelled in eddies or spinning air currents behind the cyclist.

The drag force of the air is directly proportional to the frontal area and is proportional to the **square** of your velocity. So the faster you go, the more air resistance you encounter. Even in still air, a rider soaring down a hill at nearly 50 kmph (30 mph) will be buffeted by 50-kmph (30-mph) wind. At racing speeds, virtually all the cyclist's pedal-power is spent in overcoming air resistance. Any headwind is an even greater exertion.

For this reason, many experienced cyclists prefer hills to headwinds, as headwinds are like hills that never quit.

You can test this if you have a route with a prevailing wind. Ride a flat route of, say, 10 to 15 km (about 5 to 10 miles) into the wind and time the trip, then return the same route with the wind.

The difference in time could be as much as a factor of two or three — an hour of seeming to go nowhere with great effort can turn into 20 minutes of being blown back.

There are two basic ways to minimize wind drag: minimize frontal area and streamline everything from yourself to the bike. You can do both these things to a great extent simply by pedaling in the racer's tuck — hands at the lowest point on drop handlebars, head down and back arched like an airfoil. (See Figure 3.)

Try the same windy route under the following conditions on the same bike. First ride upright, wearing a sail-like, flapping pancho on a bike fitted with panniers (side-mounted canvas "sadlebags") and flag (to maximize frontal area and minimize streamlining). Then repeat the route wearing skin-tight racing Lycra[R] and jersey and curled into a racer's tuck. Even though you may start the second trip tired from the first, you'll still find it easier.

Racing cyclists go to all lengths to reduce wind resistance and gain that last 100th-of-a-second advantage. Some even shave their arms and legs and wear airfoil-shaped aerodynamic helmets. They equip their handlebars with aerodynamic armrests not only to easily maintain the tuck, but also so that the arms direct air away from the chest and around the body, like a fairing (shape to reduce wind-drag).

These aero bars received international prominence when the trailing Greg LeMond put them on his bike in the last stage of the 1989 Tour de France and pulled ahead to trounce Laurent Fignon.

A bike wheel's spokes create tremendous drag, as you can see

ABOUT THE AUTHOR

Trudy E. Bell, who wrote "Chasing the Moon's Shadow" for the April 1991 *Science PROBE!*, is an avid touring cyclist and certified bicycle mechanic. A former editor at *Scientific American* and *Omni*, she is now senior editor for the engineering magazine *IEEE Spectrum*. Bell also teaches an introduction to bicycle touring in Maplewood, New Jersey, and writes extensively.

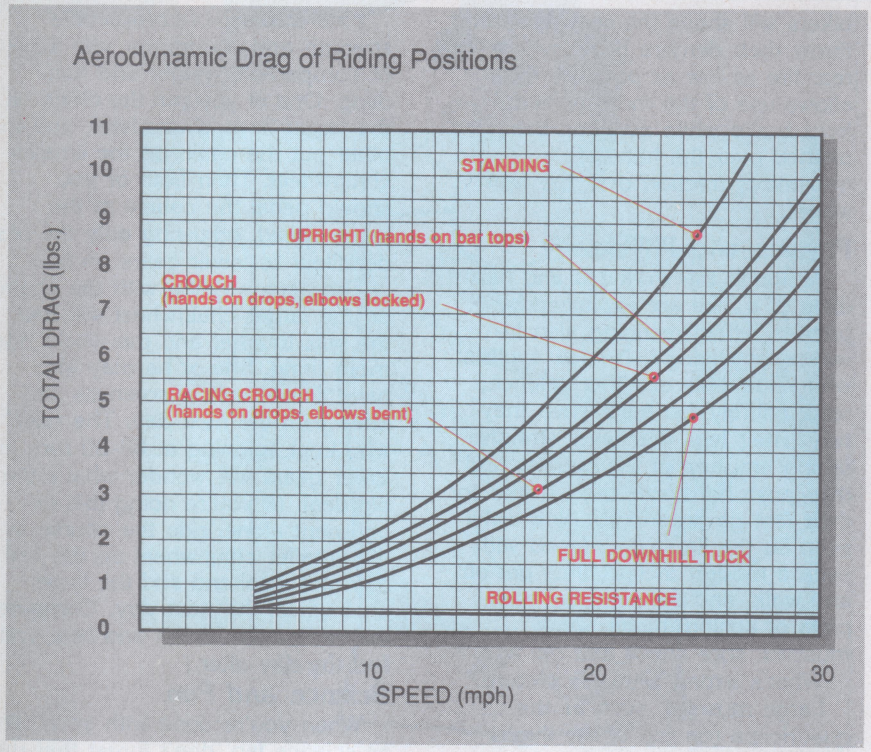


Figure 3: Aerodynamic Drag of Riding Positions; courtesy of Chester Kyle, Ph.D.; published in *Bicycling*, August 1990

for yourself by putting your face near a spinning wheel (careful!) and feeling the wind from the spokes on your cheeks.

To minimize drag, racers eliminate spokes, using either one-piece disk wheels or composite wheels with three to five air-foil shaped supports. Some racers, and many recumbent cyclists, make their whole bikes more aerodynamic by attaching a smooth fairing to the front --something often seen on motorcycles.

And, fast riders in a pack will draft each other in a paceline. Each rider takes a turn acting as a windbreak for the group, every cyclist's front tire less than a finger width from the rear tire of the cyclist in front. Drafting works, but takes concentration, steadiness and skill to avoid causing a fall — perhaps bringing the rest of the group down as well.

By the way, the main reason tandems are so fast is not that two people are pedaling the same vehicle, but that the two in-line riders experience not much more air resistance than a single rider: the frontal area is essentially only that of the larger rider.

Balancing Act

For long-distance touring cyclists, commuters and mountain bikers, the stability of the bike is much affected by the load carried. The secret to stable handling is to keep the load as low as possible, in front of the axle of the rear wheel and/or centered around the steering axis of the front wheel.

The center of gravity is a point at which all of the weight of an object may be considered to be concentrated. Any force acting on the center of gravity produces only linear motion. The center of gravity of a cyclist is about hip-height or seat height, depending on the ratio of the person's weight to the weight of the bike. A force exerted above or below your hip or saddle will unbalance you by creating a rotary motion around your center of gravity. Thus, to move a nearby rider away from you, push them gently on the hip, **not** the shoulder.

An object can be made more stable by lowering its center of gravity and increasing its base. It's tough to increase the base of a bicycle, short of towing a trailer. (Cyclists pulling a child trailer report that the handling is remarkably stable.) But in general, touring bikes and some mountain bikes have a wheelbase — distance between front and rear axle — several centimeters longer than racing bikes.

My Univega Sport-Tour has a wheelbase of 102 cm (40 in), and my Montague BiFrame mountain bike has a wheelbase of 108 cm (42.5 in). Tandems, which are very stable, have a wheelbase of about 152 cm (60 in).

You can easily demonstrate the effects of the height of the center of gravity on the stability of a bike. You'll need a good-sized backpack, handlebar bag, front and rear panniers with appropriate racks, some bungee cords, and about 20-25 kilograms (about 50 pounds) of books.

First, set out a course of around 1.5 kilometers (about a mile) around your neighborhood. It should include some stops, a couple of hills and some moderate-speed turns.

Ride the course first with the bike racks empty, just noting how it handles. Note how you steer and stop without thought and how secure you feel leaning into turns.

Now load the backpack with about half the books, swing it onto your shoulders, and head off on the course again. Note the distinctly less stable feel to the ride — how you must fight the tendency of the heavy pack to make you top-heavy as you lean into turns, or throw you over the handlebars at stops.

To verify that it's just the raised center of gravity and not simply the extra weight, try the course again with the backpack and its load bungeed onto the bike's rear rack.

Last, distribute the books evenly between left and right panniers and try the circuit again. You may even find the bike handles more securely with the load than without!

By the way, the increased stability of a lowered center of gravity is one reason experienced commuters and day tourists usually don't wear backpacks. Instead, they strap their lunches and briefcases to the rear rack.

Now, experiment with various combinations of all the books in the front and rear panniers and the handlebar bag, riding the circuit after each adjustment, and also lifting the loaded bike over a curb. Left-right distribution of the load is

crucial, eh? Otherwise, what happens? The bike keeps wanting to turn in the direction of the load because of ye olde angular momentum vector.

One of the least stable combinations is about two-thirds of the weight in rear panniers and the rest in a handlebar bag. Because of the high and forward center of gravity as well as the load being in front of the steering axis, the front end shimmies on downhills and can even cause a twisting spill. And if you try to lift the bike over a curb, you must keep it absolutely upright if you want to avoid digging a chainwheel into your calf.

Unfortunately, this combination of weight is also one of the most common among light touring cyclists, and is the cause of many cyclists hating to carry loads.

Another unstable combination is weight on a front rack above the front wheel, or even in standard front panniers. Even a couple of kilograms makes the steering sluggish, mostly because it's all in front of the steering axis and so tends to make the wheel flop from side to side.

The bike keeps wanting to turn in the direction of the load because of ye olde angular momentum vector.

But the absolutely most stable distribution of weight is indeed in front panniers — mounted on low-rider racks, which drop the weight about 20 cm (8 in) to center it around the front axle and the steering axis. In fact, loaded low riders actually make the bike **more** stable, so that cyclists in-the-know prefer to carry most of their weight low and up front. (For light touring, I use front low riders exclusively.)

Gonzo mountain bikers crashing down steep rocky slopes and climbing over logs know all about center of gravity. So do those acrobatic BMX riders who even somersault mid-air on those child-sized knobby freewheelers.

Heading down scree (small particles of rock on a hill), mountain bikers will shove the seat down and throw their derriere back over the rear tire as low as possible. This allows use of the more powerful front brake while avoiding being pitched over the handlebars. It also maximizes traction over the rear wheel.

Physics and Physiology

Although the workings and handling of a bike are explained by physics, effective riding also involves physiology. Novice cyclists, who know little of either science, work entirely too hard when they ride. Their legs are never straight during any turn of the pedals. And they push hard with each stroke so their feet go around so slo-o-owly, even on the flat. When faced with even a modest incline, they get off and walk, and the next day complain of aching thighs, weak muscles, sore knees and old age.

What's wrong with this picture?

Large muscles, such as the quadriceps (on top of the thighs above the knees) and the gluteus maximus (the buttocks) that do most of the work of pedaling, require 48 hours to recover after any anaerobic workout. This is why weight trainers work muscle groups to the point of momentary muscular failure only every other day.

The healthy heart muscle and cardiovascular system, however, has a recovery period not of 48 hours but about 5 minutes.

So physiologically, for greatest endurance over long distances and hills, you should make cycling as aerobic as possible: you should breathe hard, not push hard. How? By using the gears low enough, so that your feet are consistently spinning the pedals 60 to 80 revolutions per minute — more than once a second — even on hills. And on the flat, each push of the pedal should feel virtually effortless, almost making you feel silly for doing so little work.

You don't believe this? Here's a sure-fire demonstration, although it's not recommended for people with bad knees. Set out a course of 15 to 30 km (about 10 to 20 miles) that includes some nice, stiff hills.

Find a friend of comparable strength and endurance with a bike of comparable weight and handling. One of you put the chain on the larger front chainwheel, and the other put the chain on the smaller chainwheel. Then both of you should pedal the course at the same speed, adjusting **only** the rear derailleur to lower gears on hills.

The person riding with the chain on the larger chainwheel will find the hills tougher and the whole ride more tiring. She or he may also have some muscle soreness and knee pain the next day. The rider who kept spinning at 60-80 rpm in lower gears will wonder what's the big deal. (If you're doing this experiment alone, ride the course in the smaller chainwheel on the first day of a weekend and the larger chainwheel the next day. Compare the completion times and how you feel the day after.)

Science *and* Fun

When you're done with your bike as science lab, don't forget that the prime purpose of your metallic steed is to give you the pleasure of the sun in your face and the wind at your back. So, load up your panniers and head for the open road. And above all, enjoy! ✷

My thanks to John Kukoda of *Bicycling* magazine and other physics-type colleagues for reviewing this manuscript.

FURTHER READING

A current high school or college physics textbook such as ***Fundamentals of Physics*** by David Halliday and Robert Resnick (John Wiley and Sons, New York, 1988) will give you all the basics of bicycle physics.

Bicycling Science by Frank Rowland Whitt and David Gordon Wilson, (MIT Press, Cambridge, Massachusetts, 2nd edition, 1982) provides good background for the physics of bicycling.

The Bicycle Wheel by Jobst Brandt (Avocet, Inc., Menlo Park, California, 1988) gives a thorough engineering analysis on the most important part of a bicycle.

Bike Touring: The Sierra Club Guide to Outings on Wheels by Raymond Bridge (Sierra Club Books, 1979) is my single favorite book on the entire subject. (It **is** in print and available at many travel book shops and through Bikecentennial in Missoula, Montana.)

Also check current and back copies of ***Bicycling*** magazine (from Rodale, Pennsylvania) and ***Bicycle USA***; both periodically carry articles on the science of bicycling.

By A.K. Dewdney

From the Speed of Light to the World of Numbers

Summary

In the 17th century, Danish astronomer Olaus Roemer measured the speed of light by carefully timing the orbit of the Jovian moon Ganymede. "Genesis" shows how he did it and how you can, too, perhaps even better. For gadget-builders there is the spool motor, a wind-up powerhouse that has just three moving parts. Nature contains some impressive dynamical systems, but so does the abstract world of numbers — complete with attractors. A computer can explore these abstract worlds.

Project Ganymede

Some of the great classic experiments provide fertile ground for amateur scientists. Not only is the apparatus often simple and within reach of the amateur, the concepts and methods involved do not stretch our theoretical knowledge too far.

Besides these advantages, there is an element of history. Today's amateur scientists can stand on something like even ground with the great thinkers of the past. *They* were amateurs, too!

The great Italian astronomer, Giovanni Cassini was among the first to make accurate measurements and observations with Galileo's newfangled instrument, the telescope.

Among his many observational coups were the first measurements of the orbital period of Jupiter's moon, Ganymede. He thought Ganymede would make a perfect timepiece. Imagine his surprise when he discovered that the Jovian satellite's period gained something like 22 minutes during one half of the year, only to lose it in the next half!

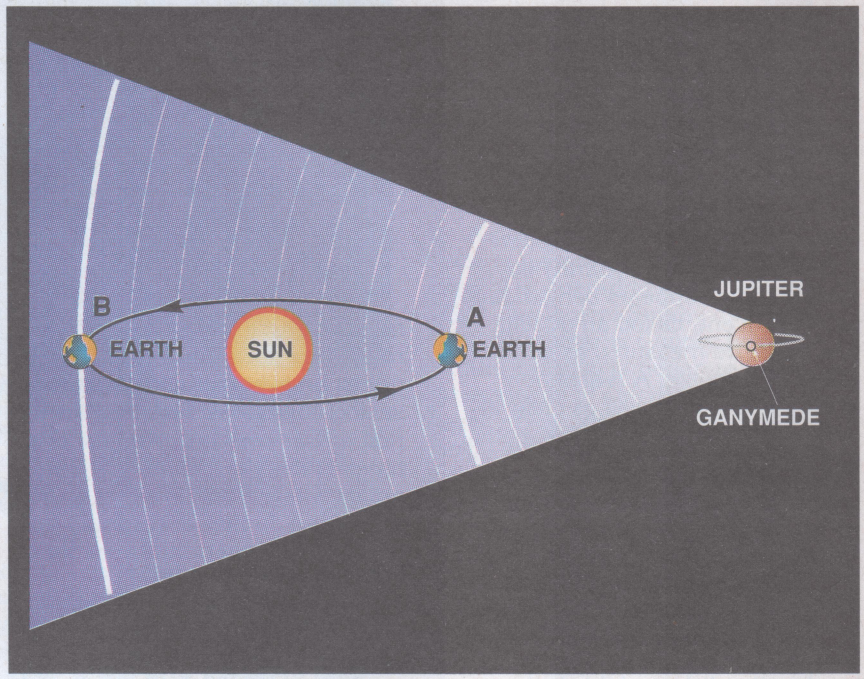


Figure 1: An observer at A sees the occultation of Ganymede 8.3 seconds earlier than the observer at B.

The problem was settled by the Danish astronomer, Olaus Roemer, in 1675. He supposed that light took a finite time to traverse the distance from Jupiter to the Earth. Thus, when Earth's orbit took it toward Jupiter, the period of Ganymede seemed to shrink, and when the Earth receded from Jupiter six months later, the period expanded.

The same thing happens when you experience the Doppler effect in a train at a signal crossing with its ringing bell. The bell is at first high-pitched, but as you pass it, the pitch drops. The wavelength of an approaching sound source will appear shorter than a receding one.

Roemer, with something like Figure 1 in mind, reckoned that the total gain in the period of Ganymede, from a point in Earth's orbit opposite the Sun from Jupiter to a point closest to the great planet, was essentially the time it took light to cross a space the distance of Earth's orbital diameter. That distance had recently been measured at close to its true value of 149.5 million kilometers.

The rest was simple arithmetic: Roemer divided the diameter by the assumed transit time of 22 minutes and obtained a figure somewhat over 100,000 kilometers-per-second.

But Cassini had unfortunately overestimated the gain in Ganymede's period by a factor of nearly three, and Romer's estimate of the speed of light was therefore too slow by the same factor. The true value for c, the speed of light, is 299,793 km/sec.

Readers with reasonably good telescopes and a clock that is accurate to the second can repeat this famous experiment in one of two ways.

The Cassini-Roemer method can be applied in two different ways, one while the Earth approaches Jupiter and one while it recedes. The former involves starting observations of Ganymede as Earth is swinging into observing range of Jupiter from behind the Sun. At such a time, Jupiter rises before dawn, as will the enterprising observer of Ganymede.

Over the next five or six months, Ganymede must be observed frequently enough to log its revolutions about Jupiter until the Earth is closest to Jupiter. At such a time, Jupiter will be high overhead around midnight. But how, exactly, does one measure the period of Ganymede's revolutions about Jupiter?

Once every 7.155 (Earth) days, Ganymede disappears behind Jupiter. This event, called an occultation, must be measured as accurately as possible. A reasonably good telescope as well as clear atmospheric conditions are essential to the measurement.

With one eye on the clock and the other on the eyepiece, the amateur astronomer waits with unbearable tension as Ganymede moves imperceptibly closer and closer to the Jovian disk. There will come a point at which Ganymede just touches the disk, and this is the moment to glance at the clock and record the time.

There is, unfortunately, considerable variation in the measurement because the "touching" is a pretty delicate judgment call, especially in view of Ganymede's imperceptible motion. Nevertheless, consistency of observational style will pay off. Are there better ways to measure the time of the occultation event? Ways that neither Cassini nor Roemer thought of?

It is not necessary to observe Jupiter every week during the five-month period of the experiment. Indeed, you may well be forced to miss the odd observation because of bad weather. If this happens, you can produce a missing observation by interpolation, noting the fact in your record book.

As Earth approaches Jupiter, there will be an overall loss of time. Ganymede's period starts off close to its true value, shrinks as the Earth approaches it, then steadily increases to its true value again. Running the experiment in reverse on the other side of Earth's orbit about the Sun, will involve an overall gain. Work out the total time lost (or gained) and you will be a mere stone's throw from working out the speed of light for yourself.

When it is all over, the amateur scientist may outdo Cassini and Roemer.

Apart from the Cassini-Roemer method, there is one that involves much less observing time but requires an even better telescope and seeing conditions. Measure the period of Ganymede during just two times in the year, namely at the points where Earth is either approaching Jupiter or receding from it at Earth's own orbital velocity of 29.8 km/sec.

During either period, measure Ganymedean occultation times as frequently as you can over several weeks to arrive at the best possible average time for the satellite's period.

If P1 is the period you measure as the Earth recedes from Jupiter and P2 is the period during approach, a simple formula yields c, the velocity of light:

$$c = 29.8(P1+P2)/(P1-P2)$$

In the Cassini-Roemer method, an ideal outcome would be a measured periodic change of around eight or nine minutes. In the second method, you will have to be really on your toes. The discrepancy between the two measurements, P1 and P2, should be in the neighborhood of 30 seconds!

When it is all over, the amateur scientist may outdo Cassini and Roemer. On the other hand, he or she may do considerably better. Either way, there is the greatest satisfaction imaginable in having made your own measurements and you will, at least, have seen for yourself that the speed of light is finite.

Spool Motors

We have all wound up the motor of a toy car or doll in our day. The car barely made it across the living room before it quit. The doll took maybe 20 steps before it ground to a halt and fell on its face. Imagine a wind-up motor that out performs the standard type in two ways: It runs 10 times longer, and it has only half as many moving parts — three to be exact.

The idea for the spool motor occurred to me in my youth as I tried one day to imagine a wind-up motor that would power a model airplane far beyond the range of the standard rubber band engine. For those unfamiliar with the classic rubber band motor, it consists of a single rubber band stretched from the back of the propeller hub at the front of the aircraft to a special post inside the tail.

When the propeller is laboriously turned, the rubber twists around and around inside the aircraft. When the propeller is released, the energy stored in the twisted band plays out through the hub. The propeller turns and the aircraft flies. But not for long.

It seemed possible, somehow, to confine all the deformation of the rubber to a small volume and, simultaneously, to get a lot more rubber into the act. Would a spool work? What about two spools? Aha!

Figure 2 shows two spools, one small and one large. The axles of the spools are connected by direct gearing or a drive belt. A length of rubber band has been partially wound up on the large spool. It runs over a special pulley onto the second spool.

If one started with all the rubber wound on the smaller spool with very slight tension, imagine what would happen when the larger spool is turned in a direction that winds the rubber onto it. As the rubber is taken up on the larger spool, it stretches. A given length of rubber that occupied a certain portion of the small spool's circumference is now being asked to occupy a considerably greater circumference on the large spool. Energy is being stored on the large spool!

When all the rubber is wound onto the large spool in this manner,

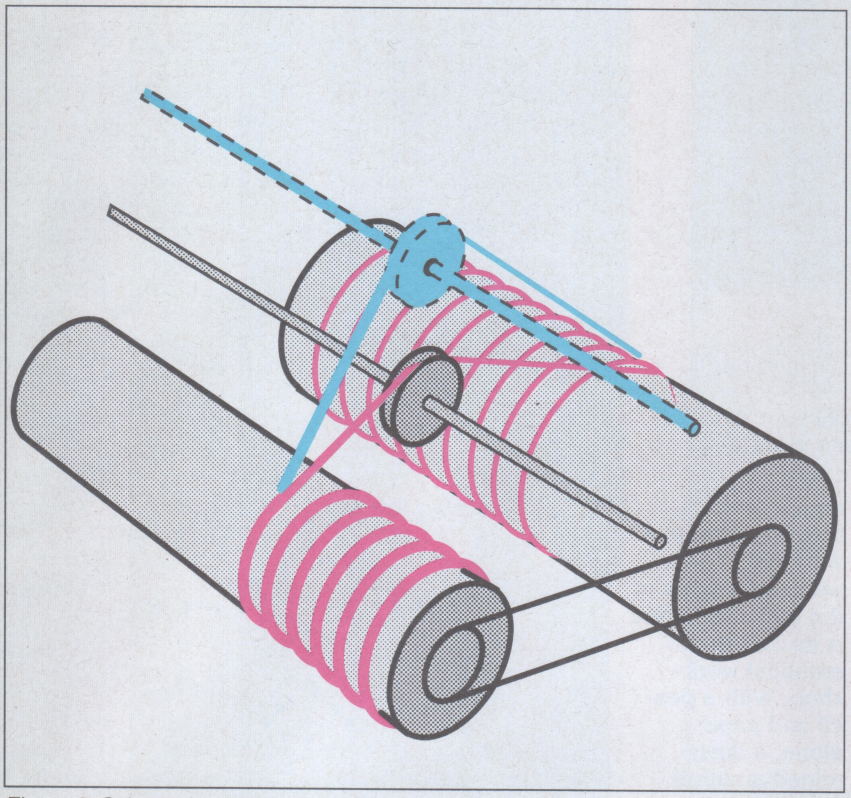


Figure 2: Schematic of a spool motor

simply release the motor. The elastic "wants" to be on the smaller spool and it will all wind onto it as the motor runs.

The special pulley plays an important role in the spool motor. It is free to slide on a bar that is parallel to the two spools.

The bar itself has two positions into which it may click. In one position, farther from the twin spools, the tension in the free rubber matches the tension in the large spool. The bar must be in the first position when the motor is being wound up. Before it is released, however, the bar must be clicked into the other position. As the rubber plays out from one spool onto the other, the pulley will slowly travel along the bar, tracking the spiral layers of rubber.

I have built a simple spool motor from Meccano®, a construction kit similar to the Erector® sets. But my motor has done little more than demonstrate the principle as workable. What intrepid builder out there will construct a truly elegant spool motor?

It will help if the thinnest available elastic material is used in place of a rubber band. This way, the greatest amount of energy can be stored without resorting to more layers of windings than the spools can accommodate.

The motor I have just described has five moving parts. How can I claim just three? The well-known Carnegie Mellon roboticist and polymath, Hans Moravec, suggested the following simplification during a conversation one day: Why not put the two spools on the same axle? Both would then comprise a single moving part, and the drive belt or gearing would be eliminated.

Would such a motor be possible? It all depends what you do with the pulley.

One can imagine a really big spool motor that can be used in automobiles. If a relatively short length of powerful steel spring were wound between two spools equipped with grooves to receive the individual coils, such a motor would eliminate the high gas consumption we endure in city driving.

Every time a car so-equipped approached a stoplight, the driver would only have to press a pedal that combined the functions of spool motor clutch and ordinary brake. Pressed part way in, it would engage the spool motor. Pressed all the way in, it would operate the brakes. The winding spool would slow the car right up to the point where the brake is applied.

When the light turned green, releasing the pedal would automatically reverse the spool gearing, and the car would bound forward with the energy that it stored on stopping!

Numerical Dynamics

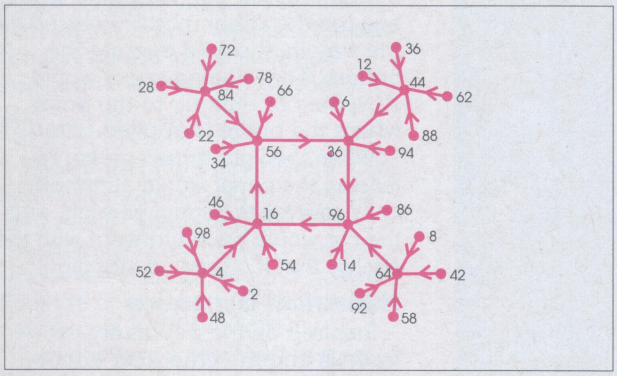
Inspired by the popularity of fractals and the emerging importance of chaos as a new physical paradigm, the last decade has seen an enormous burst of interest in dynamical systems. Natural systems range from vibrating leaves to the great weather machine itself. Less natural systems such as double pendulums and oscillating circuits inhabit the laboratory. And, to be sure, the laboratory has contributed its share of not-so-natural systems. But the most artificial systems of all are numerical. They have no physical counterpart at all.

Numbers systems display dynamics all their own. It all depends on using a numerical operation, such as squaring, to reproduce the effect of a force.

Take, for example, the system of two-digit numbers from 00 to 99 and pretend that each number is a state that the system might be in at any one time. This system moves from state to state under the influence of a mathematical "force" or operation that uses squaring. It moves each two-digit number WX into another two-digit number YZ as follows: square the number WX to obtain a number that has at most four digits. Now extract the last two digits of this number. These are YZ.

For example, when WX happens to be 72, the square of 72 is 5184. The last two digits, YZ, are 84. Another way to describe the same operation will become important a little later: square the number and take the remainder on division by 100.

You can draw a picture of this dynamical system by placing 100 points on a sheet of paper and labeling each of them with one of the two-digit numbers. From every point you can draw an arrow to another point. Simply look up the number that corresponds to each point, square it, extract the last two digits and locate the point with that



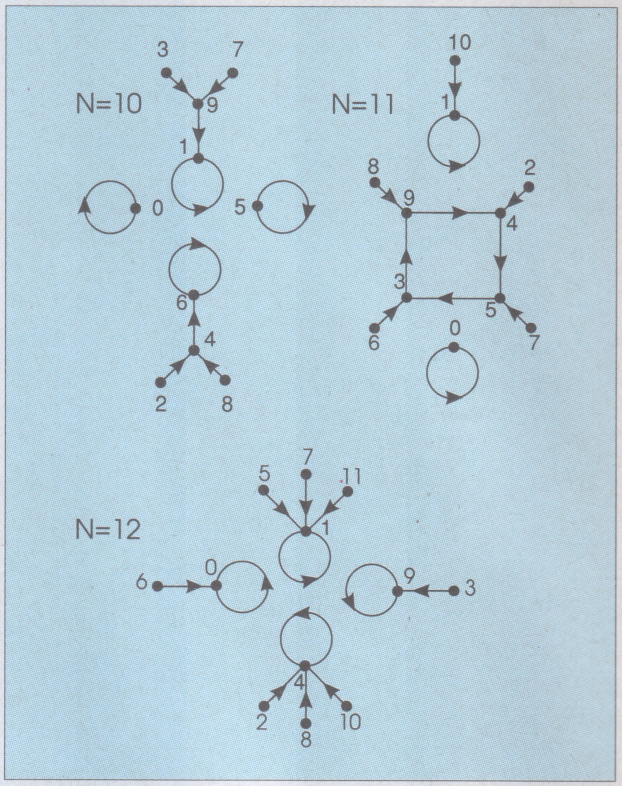


Figure 3 (above). Part of the iteration diagram for the 100-System; and Figure 4 (right). Complete diagrams of the 10-, 11- and 12-systems

label. Now run the arrow from the first point to the second one. The end result is a pretty-looking picture called an iteration diagram.

If it isn't pretty to begin with, it is always possible to re-arrange the points to make a simple symmetrical pattern resembling the ones in Figure 3. The diagram is the phase portrait of the numerical dynamics of the system.

Figure 3 shows part of the diagram for the 100-number system described. Note that repeated applications of the operation drive the system from state to state along a path or trajectory in the diagram until it begins to cycle among just a few states. Such a cycle is part of the system's attractor. For example, state 72 leads through 84 to the attractor consisting of the endless cycling states: 56, 36, 96, 16. Here the numerical dynamical system can be considered to be in equilibrium.

As you may have guessed, there is more than one system to be explored in this abstract realm. In fact, any number can serve as the upper limit of such a system, just as 100 does for the 100-number system: Take, for example, the number 57. Here the same modular operation is used: Square the number and take the remainder on division by 57. For example, if the number is 23, then 23 squared is 529. The remainder on dividing 529 by 57 is 16. This is the sate to which 23 goes under iteration.

Figure 4 shows the iteration diagrams for 10, 11 and 12, each nicely laid out to show the structure. Such diagrams have a lore and a logic all their own.

In certain respects, amateur mathematicians have the easiest calling of all. They require no expensive lab equipment, no messing around a work bench, no waiting for parts in the mail. The mind is its own mathematical workshop. With a pencil and paper alone, a determined amateur can, in the course of an evening, develop diagrams for many of the smaller systems from 10 to 100.

For ease of exploring numerical dynamics, nothing can replace a personal computer. In your favorite language, write a simple program that takes a single number, N, as input. The program will then calculate a list of number pairs. The first member of each pair will be 1, 2, 3, and so on. The second member will be the first number squared modulo N. When N is 100, for example, the 37th entry in the computer-generated list will be (37, 69) because the square of 37 is 1369. On the basis of this list, you can draw an iteration diagram much more quickly because all the hand calculations have been eliminated.

Sooner or later, more ambitious souls will search for ways to automate the diagram-drawing process itself. Imagine merely having to type in the number N, and there, within a few seconds, a pretty iteration diagram appears on your screen. I know of no one who has done this.

And what a boon it would be for the mathematically-minded prober! Many interesting questions could be explored with such a tool. For example, do all iteration diagrams come in separate pieces? Find one that is connected. What properties must N have in order that the diagram be all of a piece? What is the greatest number of pieces that a diagram can have in relation to N? Watch out! The deeper you get into these questions, the harder it will be to leave their study. ✷

FURTHER READING

Exploration of the Universe by George Abell (Updated Brief Edition, Holt, Rhinehart and Winston, 1973).

"Spool motors — compact storage of a stretched elastic medium," Mechanism and Machine Theory by A. K. Dewdney (Pergamon Press, Vol. 13, 1978, pp. 245-250).

The Armchair Universe by A. K. Dewdney (W. H. Freeman, 1989).

ABOUT THE AUTHOR

A.K. Dewdney, who for eight years wrote columns about computers and mathematical recreations for *Scientific American*, is a professor of computer science at the University of Western Ontario. He founded *Algorithm*, a recreational and educational computer programming magazine. Professor Dewdney's interests include amateur astronomy, paleontology, botany and biology.

By William Barden Jr.

Personal Computers and Astronomy

Summary

You can use your computer to simulate the night sky using relatively inexpensive computer programs to display the position of thousands of astronomical objects from any vantage point on Earth. These programs can also display the orbits of planets and comets, conjunctions of objects, and eclipses of the Sun and Moon.

Like many *Science Probe!* readers, I've always been interested in astronomy — interested enough to take pictures of a solar eclipse for a science fair project, grind a mirror for a small reflector telescope, take several college courses in astronomy, and watch everything related to astronomy on Public Broadcasting Service.

I've also been fascinated by planetarium shows. When home computers became a reality, I had some fleeting thoughts about designing a computerized planetarium. If you've had the same thoughts, let me offer some advice: Forget it!

Now, there are now programs that will display 10,000 astronomical objects on your computer's screen, allow you to select a date (from antiquity to far in the future), set any vantage point on Earth, display precise planetary orbits, and display all the satellite orbits of Saturn in close-up view. What's more, these programs are relatively inexpensive considering the data and calculations that are involved.

In fact, there's even a wealth of programs, data and astronomical

The CompuServe Astronomy Forum provides an exchange of ideas among users interested in astronomy and space, in addition to a database of programs, tutorials and graphics images.

```
#: 94339 S8/Telescopes/Hardware
    20-Nov-91  14:58:45
Sb: #94180-#Getting Started
Fm: David XXXXXX 76074,XXXX
To: Rick XXXXXX 76030,XXX (X)
I AM ALSO VERY INTERESTED IN STARTING THIS HOBBY. I DO NOT
KNOW WHICH KIND OF TELESCOPE TO GET AND HOW POWERFULL
(MAGNIFICATION). DO YOU KNOW THE DIFFERENCE BETWEEN
TERRESTRIAL & ASTRONOMICAL. WE JUST BUILT A DECK AND WANT
TO START ASAP. ANY HELP OR DIRECTION WOULD BE VERY MUCH
APPRECIATED.
...
#: 94347 S8/Telescopes/Hardware
    20-Nov-91  17:53:47
Sb: #94339-Getting Started
Fm: SKY & TELESCOPE 70007,XXXX
To: David XXXXXX 76074,XXXX
David:  The only difference I know of, between a
terrestrial and an astronomical telescope, is the
orientation of the image.  Astronomical telescopes avoid
unnecessary lenses like the plague — in order to keep
light losses as low as possible.  In a terrestrial
telescope, which is normally used in daytime, there is
plenty of light.  Thus, they contain extra prisms or lenses
to provide an upright image. The main rule when buying a
telescope for the stars is to look at the aperture (size of
the main lens or mirror), and *not* the magnification. You
can always get a variety of eyepieces to give you whatever
magnification you want.  But, the aperture determines the
light-gathering power and the theoretical resolution.
These are two things that you *can't* change with any
accessories later.
   — Roger
...
#: 94386 S8/Telescopes/Hardware
    21-Nov-91  05:14:42
Sb: #94275-#Getting Started
Fm: Robert XXXXXX 72740,XXXX
To: Rick XXXXXX 76030,XXXX (X)
Rick,
While not as cheap as a December issue of Astronomy
magazine, there is an excellent, new book "The Backyard
Astronomer's Guide" by Terence Dickinson & Alan Dyer (about
$40).  This book covers virtually all aspects of amateur
astronomy from equipment thru use.  While not cheap,
spending this $40 up front may help you save big $$  later
on and give you some ideas you may never have come up with
on your own. Good luck (and remember: a new telescope = 2
weeks cloudy skies, a new major accessory = 1 cloudy new
moon weekend).  Bob C.
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pictures on data communications services such as CompuServe®, just waiting for you to download them for the cost of a telephone connection.

In this column, we'll take a look at some astronomy software, review three representative commercial programs and describe some of the public domain offerings. I think you'll be as enthused as I am after reading about what's available.

A Caveat

First, let me describe what these programs are *not*. I visualize the ideal astronomy program as a ride through the universe, a composite of Jet Propulsion Laboratory planetary shots and PBS's "Project Universe" — with great screen displays and animated tours. The programs described here are definitely more sedate. Although some include visuals, there is no animation and few dramatic displays. And there probably won't be until more is done in CD-ROM system development.

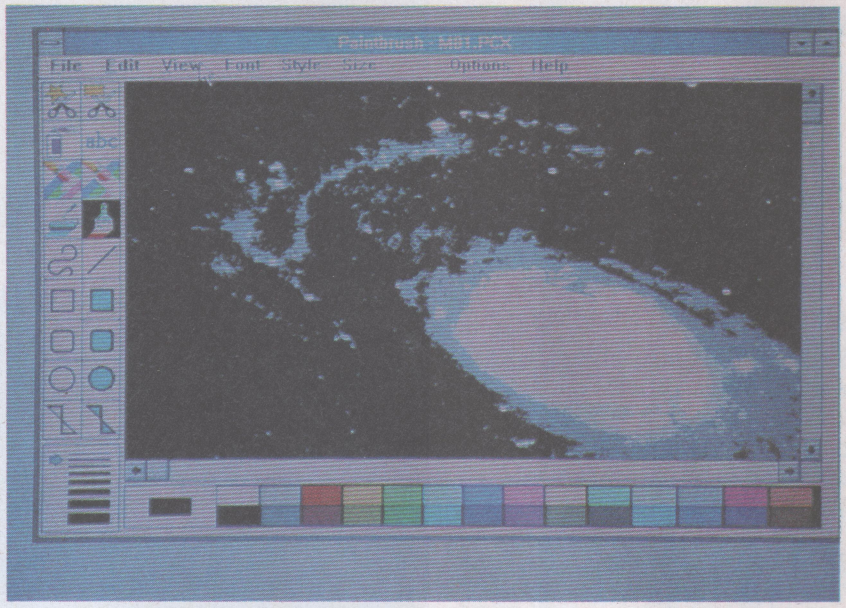
But, once you accept that, the programs are still impressive, offering a complete visual catalog of astronomical objects on your home computer system. Ptolemy, Brahe and Galileo would be amazed!

The CompuServe Space/Astronomy SIG

Before describing three commercial astronomy programs, let me describe some software that's free, or nearly so. There are many commercial and individual data communications and bulletin board systems that provide forums and databases on science-related topics. One of the best, if not the best, for astronomy topics is CompuServe. It is one of the most widely used data communications services (about 700,000 subscribers).

CompuServe has a Space/Astronomy Special Interest Group (SIG), which offers a wealth of data about the space program, space probes, artificial satellites and mainline astronomy.

The Astronomy subsection "forum," a message area, has these menu items: Forum Help; Getting Started; Satellite Observing; The Solar System; Deep Sky Astronomy; Astrophotography; Astronomy Software; Telescopes/Hardware; Activity; Club News; Graphics; Cosmology; *Sky & Telescope* Magazine; Astro-Facilities; Swap and Shop; Astronomy Databases; New Uploads.



Woodie F. Morris, used with permission

Typical downloaded graphics image from the CompuServe Astronomy Forum. Most images are in CompuServe .GIF format, which can be translated to other formats. In this example, the image is displayed under Windows *Paint*.

The example on the first page shows typical messages from this forum, edited to delete the author's name and CompuServe ID.

In addition to messages, however, there's an extensive database of programs and graphics images. Both the programs and images can be downloaded from the CompuServe database to your own computer system.

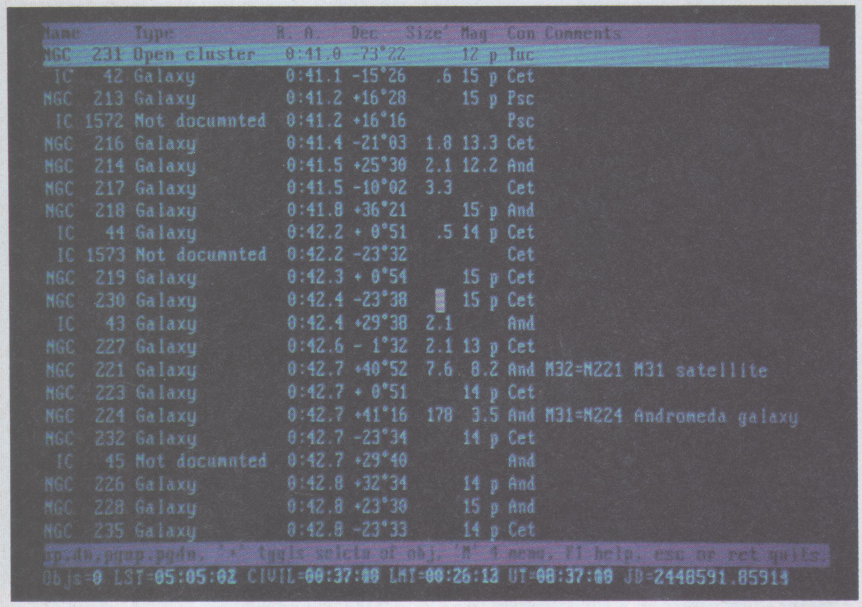
Listed below is a sampling of some of the hundreds of programs and images available:

GASPR5.GIF	Gaspra, processed image.
POL-DE.EXE	Personal Observing Log Package.
GASP3M.ZIP	Three modified Gaspra Images.
SOP914.	STS ORBIT PLUS Ver 9146 for PC.
WU120E.ZIP	Decode/display telemetry from OSCAR satellites.
SARA.ZIP	Radio astronomy satellite SARA-OSCAR 23 description.
SARA_B.ZIP	Programs compute position of Jupiter and SARA.
CSC101.EXE	Cheap Setting Circles.
WRT012.GIF	Comet Levy in May 1990.
EJASAM.TXT	Announcement of article on Optical SETI.
GASPRA.GIF	Gaspra from GALILEO from 10,000 miles!
N11CLR.GIF	NOAA 11 Weather Satellite Image 11/15/91 1945 UTC.
PERSPE.GIF	Color image of Venus from Magellan.

Some of the programs are trivial, but many are incredibly detailed and useful. The graphics images are created from observations by amateur or professional astronomer, satellite imagery, or from space probe shots. Many are in color. The photograph above shows a typical downloaded graphics image.

Although the service is free, and programs and graphics can be downloaded without charge, there are still expenses connected with CompuServe itself and hardware and software for your computer system. You'll need a 300- to 2400-baud modem card or external modem (an adequate 1200--baud modem card costs about $50).

You'll need a data communications program (ProComm Plus is popular and comprehensive at about $80, discounted, or get it as "shareware" with a donation re-



The *NGC 2000.0 Database/Optimizer* displays a list of selected celestial objects from a database of 13,000. It can be used to list items in a particular part of the sky or to find any specific object.

quested). You'll also need about $25 (discounted) for a Compu-Serve "starter kit." Thereafter, typical charges run about $8 to $14 per hour, depending upon your geographic area and modem speed.

With a 2400-baud modem, you can scan about 72,000 words per hour at about $14 per hour, so there's a great deal of information you can access at a reasonable cost. Members in the group are more than happy to answer questions from beginners or other members.

NGC 2000 Database and Optimizer

The first set of programs that we'll review is Sky Publishing's $49.95 (list) *NGC2000.0 Database and Optimizer* program. As you probably know, celestial objects — individual stars and constellations, star clusters, and galaxies — appear to rotate in the sky around a point near Polaris, the North Star in the Northern Hemisphere. Stars and constellations appear to rise and set depending upon your latitude, longitude, time of year and time of day. Planets and their satellites follow their own paths around the sun.

There are a great many star maps that locate the more familiar astronomical objects. If you have a telescope with setting circles, you can consult an astronomical almanac or ephemeris to find the stellar coordinates of objects based on two coordinates — right ascension and declination. Moving two axes on the telescope to the proper index values will point it at the location of the object in the sky.

Now there are even relatively low-priced automatic telescope drives that will point a telescope for you, given the right ascension and declination coordinates. This simplifies finding some of the fainter objects that can't be seen by the naked eye. Most people can see only a magnitude 6.0 stellar object, but a pair of binoculars enables the viewing of objects up to magnitude 10.0, increasing the number of viewable objects from about 2500 to 50,000.

The *NGC 2000 Database* is a description of 13,226 stellar objects — a computerized file that describes each object by name, type, right ascension and declination coordinates, angular size, magnitude, and other text. Although 90 reference stars are listed, the NGC list consists primarily of star clusters, galaxies, nebulas and other "distant sky" objects.

Want to find the Ring Nebula? Look up NGC 6720 or "Ring" and point your scope. Want to find the Sombrero Galaxy? Look up NGC 4594 or "Sombrero."

The *NGC Database* is usable as is, with some minimal processing by a word processor or other simple program. However, the *NGC Optimizer* makes the data in the database a lot more accessible. With the *Optimizer*, you can look for a specific range of objects by NGC starting and ending number, specific text, position in the sky, proximity to other objects, and a variety of other means.

The *Optimizer* is "menu driven" with pop-up, Windows-like menus, and you'll be able to navigate around the program easily. The display can be color, black and white, or red (for night viewing). A large format display of coordinates is also available for night viewing from a distance while adjusting equipment.

Although it's not a flashy program, the *NGC Database/Optimizer* is accurate, extremely fast (searches on an 80286 or 80386 system are almost instan-taneous) and provides a comprehensive database of useful information, accessible and worth the price.

Distant Suns

While the *NGC 2000.0 Database/Optimizer* provides a fast search and list of celestial objects, *Distant Suns* carries computerization to the next logical step, displaying the data in graphical form to simulate a planetarium.

Distant Suns, by Virtual Reality Laboratories, is a $129.95 (list) program designed to run under Microsoft Windows. System requirements are an IBM PC compatible computer with 640K RAM, EGA or VGA video, a hard drive with at least 5.5 megabytes available, and Microsoft Windows 3.0 or greater. *Distant Suns* is also available for Amiga personal computers, but we'll describe the PC version here.

Unless you have Windows installed, you cannot run the program. *Distant Suns*, however, is impressive and might be a good motivating factor for purchasing Windows if you are interested in astronomy. Windows costs about $90 discounted. It can be installed in about 30 minutes. Once installed, you can bypass it entirely or use it only for individual programs such as *Distant Suns*.

To say that *Distant Suns* is a planetarium program is misleading. It is certainly that, but much more besides. The basic view is from Earth in either of two view modes:

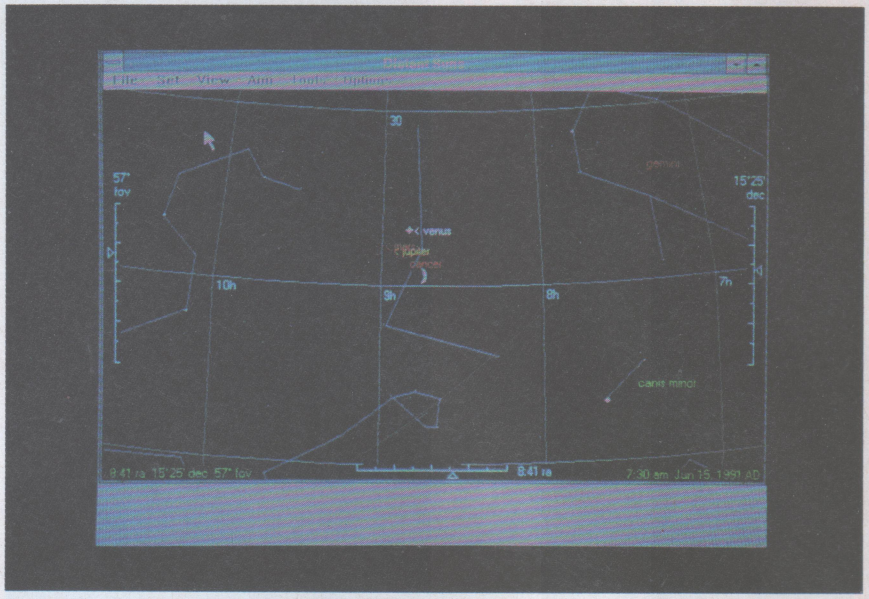
equatorial or horizon. The horizon view mode is shown in the bottom photograph at left. It is a view of the sky with a certain azimuth (compass heading) and altitude (angular distance above the horizon). The second view mode is equatorial and displays the sky as if there were no Earth underneath.

The field of view can be changed from 3 to 180 degrees. With a field of view of 180 degrees, you'll see the entire sky. A narrower field of view is like zooming in on a portion of the sky with binoculars or a telescope.

Distant Suns uses color effectively. You can, for example, create a night sky that almost exactly matches what you'd see outside, with subtle color shadings of celestial objects. The program uses a database of up to 9100 stars and 450 galaxies, nebulas and star clusters. A subset of this database displays all stars brighter than magnitude 5.25 — about 2200 stars.

Of course, the real power of such a program is to modify this basic display of reality on demand. Here are some of the modifications and enhancements you can perform on the night sky:

- Altering the geographic position of the viewing. For example, you could specify a latitude and longitude corresponding to Moscow, Santiago or London. The display will then update, displaying the sky as viewed from that location.
- Alter the date of viewing. You might specify a date corresponding to archaeoastronomical measurements made by the Mayans or Egyptians, for example. Any date from 4713 to 10,000 A.D. can be specified. Together with being able to specify a world location, this feature lets you view any significant astronomical event —occultations, planetary alignments, eclipses and others.
- Alter the number of objects to be viewed. You can select or deselect the Sun and Moon, planets, NCG objects, Messier objects, stars or your own objects. Turning off everything but the planets, for example, lets you rapidly determine the number and position of all planets from your viewpoint. You can also limit the stars to be displayed by magnitude, displaying, say, only magnitude 4.0 and greater stars.
- Display various tags, such as names of constellations, planets, bright stars, NGC and Messier objects, types of stars, and so forth.
- Display various sky overlays. With this feature you can overlay constellation outlines, positions of solar system objects, the local horizon and altitude, the celestial equator, the ecliptic (plane of the solar system), and the celestial grid. Of course, once displayed, the lines may be easily deleted.
- Search the sky for various objects. Just about any object in the database may be found by selecting a search mode—planets, constellations, NGC and Messier objects, stars by name, stars by Yale Bright Star ID, and stars by Harvard ID. Once found, the object will be centered and highlighted.
- Add your own objects. You may also add additional items to the database for display. If, for example, you are interested in displaying an unknown object, you can specify the location, magnitude and type of object. Up to 3000 "user items" can be added and be conditionally displayed.
- Print the current screen. At any time you can print the current display on any of the system printers defined in Windows. A typical printout is shown in above. This is a handy feature for making real observations. You can display the current sky (or the way the sky will be later in the evening), call up the display and print out a star chart in a few seconds!
- Bit-mapped images. *Distant Suns* also allows you to display full-color images of anything you care to save. Several examples are included in the basic database, such as galaxies, space probes and the like. Many examples of astronomical objects can be found in the CompuServe Space/Astronomy SIG.
- "Stepping though" time. A manual clock feature of *Distant Suns* allows you to step through astronomical events such as eclipses or conjunctions. In this mode, time does not change until you tell it to, and then by a fixed amount from seconds to years.



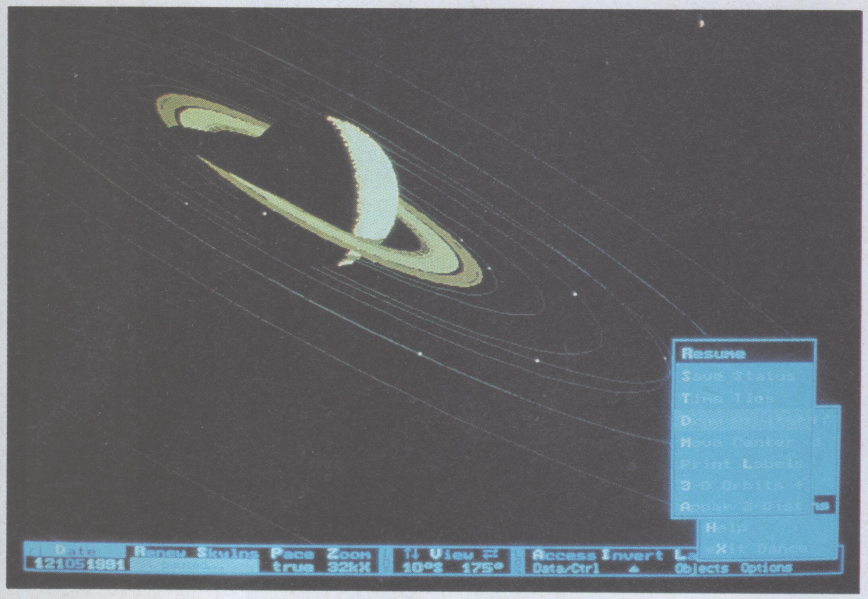
Distant Suns provides a planetarium-like view of the sky in a Microsoft Windows environment. This shot shows the triple conjunction of Mars, Venus and Jupiter on June 10, 1991.

An 80-page manual accompanies *Distant Suns*. About half of it describes operational details and the remaining half is a tutorial.

I personally recommend *Distant Suns*, especially if you're an active Windows user. The "point and click" mouse operation makes the program easy to use, and I like the appearance of the displays and printouts.

Dance of the Planets

The third astronomical program we'll look at is *Dance of the Planets*, a $195 (list) simulator program by A.R.C. Science Simulation Software. *Dance of the Planets* requires a PC compatible with 640K of RAM and DOS 3.0 or greater. Although a hard disk is not mandatory, it will help. In addition, a math co-processor (8087, 80287, etc.) greatly



Dance of the Planets allows close-up views of planets and other solar system objects. This shot shows Saturn from space.

speeds up the computations and displays.

Like *Distant Suns*, *Dance of the Planets* simulâtes the night sky in planetarium fashion. But, *Dance* is also a space simulation program, relying heavily on computations to calculate and simulate gravitational effects among the objects displayed. In addition, *Dance* provides an external view of the solar system from several points away from Earth. You can view the solar system from afar, for example, just as you would from a long ranging space probe.

In addition, solar system objects have enough resolution so that you can get a "zoom" view of planets, the Moon and other objects. You can, for example, progressively zoom in on Saturn until most of the screen is filled with the planet and its rings. At certain times you'll see the planet with rings edge-on; at other times, the rings will be at an oblique angle.

Bear in mind that zooming in is not instantaneous — each new zoom will require from tens of seconds to several seconds to update.

Dance also displays stereo images, with a pair of familiar red- and blue-lensed glasses included.

Dance has a database of 9097 stars, 1320 deep sky objects (galaxies, star clusters, pulsars, quasars, radio sources, and x-ray sources), 88 constellations, 4650 asteroids, 1300 comets, and, of course, all 9 planets and their 61 satellites.

Dance allows you to do most of what *Distant Suns* does:

- Alter the geographic position of the viewing from Earth.
- Alter the date of viewing, from 4680 B.C. to 10,000 A.D.
- Alter the number of objects to be viewed.
- Display various name tags of planets, satellites, asteroids and comets.
- Display various sky overlays.
- Search the sky for various objects.
- Print the current screen in Epson or Hewlett-Packard Laserjet format.
- Alter the simulation time.

The real beauty of *Dance*, however, is its powerful simulations. You can view any simulated past or present event with great accuracy and detail — passages of asteroids close to Earth, retrograde motion of Mars, the 1991 solar eclipse and comet orbits. All simulations can show an overlaid path of up to 20 active objects, orientation grids and labels. The photographs on the previous page show typical displays.

The 140-page manual supplied with *Dance* is both an operational manual and an excellent tutorial.

I recommend *Dance of the Planets*, especially for computer users who are interested in more than just star charts. If you want to see the gravitational effects and physics behind celestial events and to view events in detail, *Dance of the Planets* is unmatched.

The Future

The programs reviewed here are the precursors of other astronomical programs that will be available. Multimedia for personal computers is coming into its own, with CD-ROM diskettes that hold about 1,500 full-color VGA images or 62 million words or a combination of images and text. Look for more elaborate astronomy programs as this technology develops.

In the near future we will be able to take that ride through the universe, or to view spectacular planetarium software. In the mean-time, the products and services mentioned here are impressive in their own right. ✳

RESOURCES

CompuServe. CompuServe Incorporated, 5000 Arlington Centre Blvd., Columbus, Ohio 43220; (800) 848-8199.

NGC 2000.0 Optimizer Diskette. Sky Publishing Corporation, P.O. Box 9111, Belmont, Massachusetts, 02178-9111; (617) 864-7360.

Distant Suns. Virtual Reality Laboratories, 2341 Ganador Court, San Luis Obispo, California 93401-9826; (805) 545-8515.

Dance of the Planets. A.R.C. Science Simulation Software, P.O. Box 19558, Loveland, Colorado 80539; (303) 667-1168.

Here are several other suppliers of astronomy software and books. None have been reviewed:

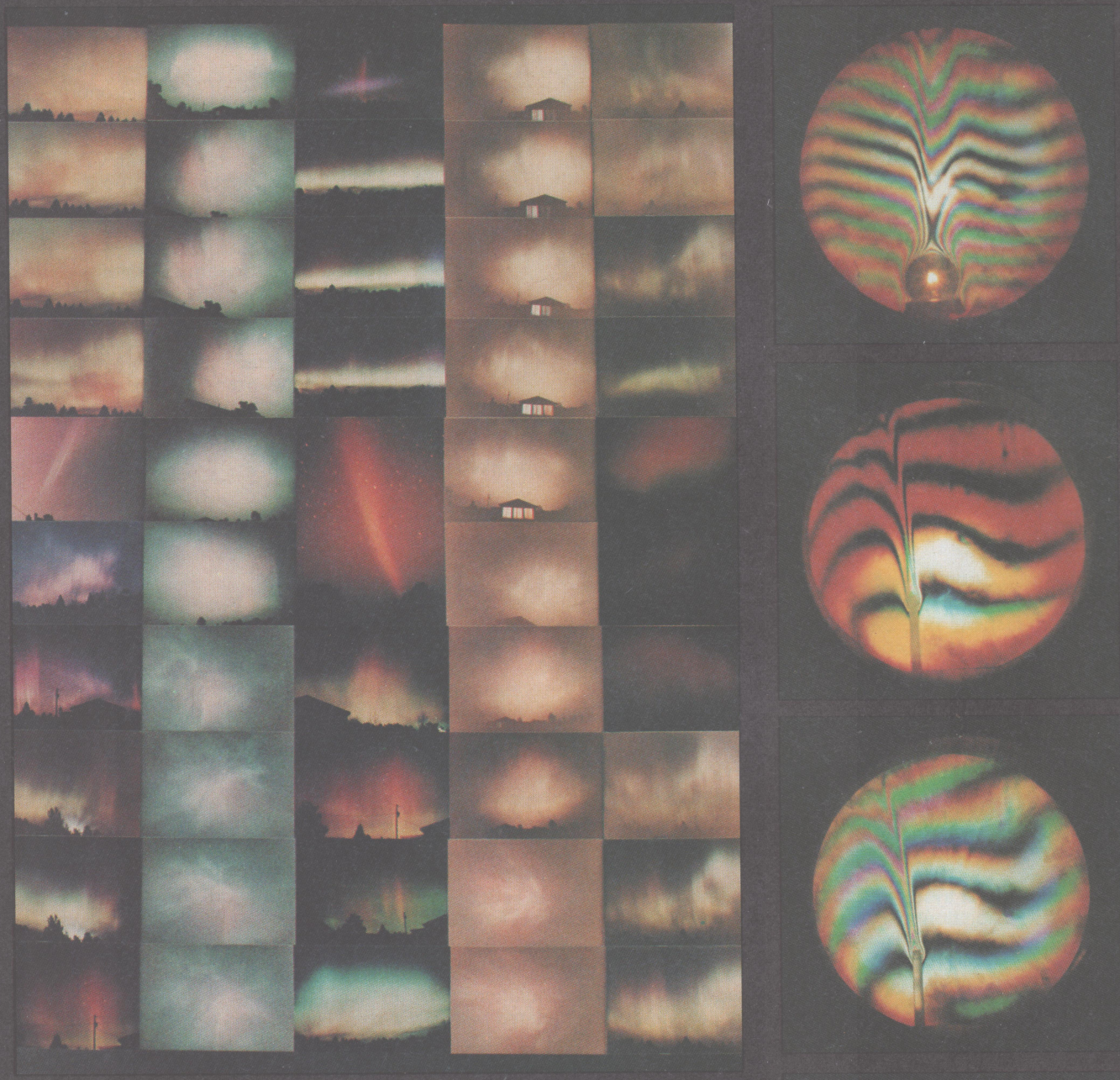
Astronomy with Your Personal Computer by Peter Duffett-Smith, Cambridge University Press, 40 West 20th Street, New York, NY 10011-4211, $27.95 paperback; (800) 872-7423.

Computerized star atlas and many astronomy utilities are available from Willmann-Bell, Inc., P.O. Box 35025, Richmond, Virginia 23235; (800) 825-STAR.

Planetarium programs, object trackers, other utilities: Zephr Services, 1900 Murray Ave., Pittsburgh, Pennsylvania 15217; (800) 533-6666.

ABOUT THE AUTHOR

William Barden Jr. has written 35 books and hundreds of magazine articles about personal computers. He has an abiding interest in astronomy and was able to view and photograph the annular eclipse of the Sun last January 4.



Above: A remarkable collection of photographs of the aurora borealis or the northern lights made by James Fantozzi of Grove, Illinois, during 1990. (Mamiya Sekor, 16- and 50-mm lenses, various films.)

Right: Gustavo Rodriguez-Zurita of Veracruz, Mexico, photographed this series of interference patterns produced by a common-path interferometer made using holographic zone plates. Convective currents are caused by heat sources (lamp in the top photo, cigarette in the center two photos, no heat source disturbance in the bottom photo). Rodriguez-Zurita explains that, "A zone plate is an array of circular stripes alternately opaque and transparent. It works as a lens with high chromatic aberration. I arranged two identical zone plates around the center of curvature of a concave spherical mirror so that the image of one plate matched the other. The illumination was provided by a small lamp behind one of the plates." (Pentax Spotmatic II, 50-mm macro lens at *f*/4, Kodacolor 400.)



Above: This dragonfly (order Odonata) was photographed by James Fantozzi of Grove, Illinois. (Mamiya Sekor with extension rings, Fuji 100.)

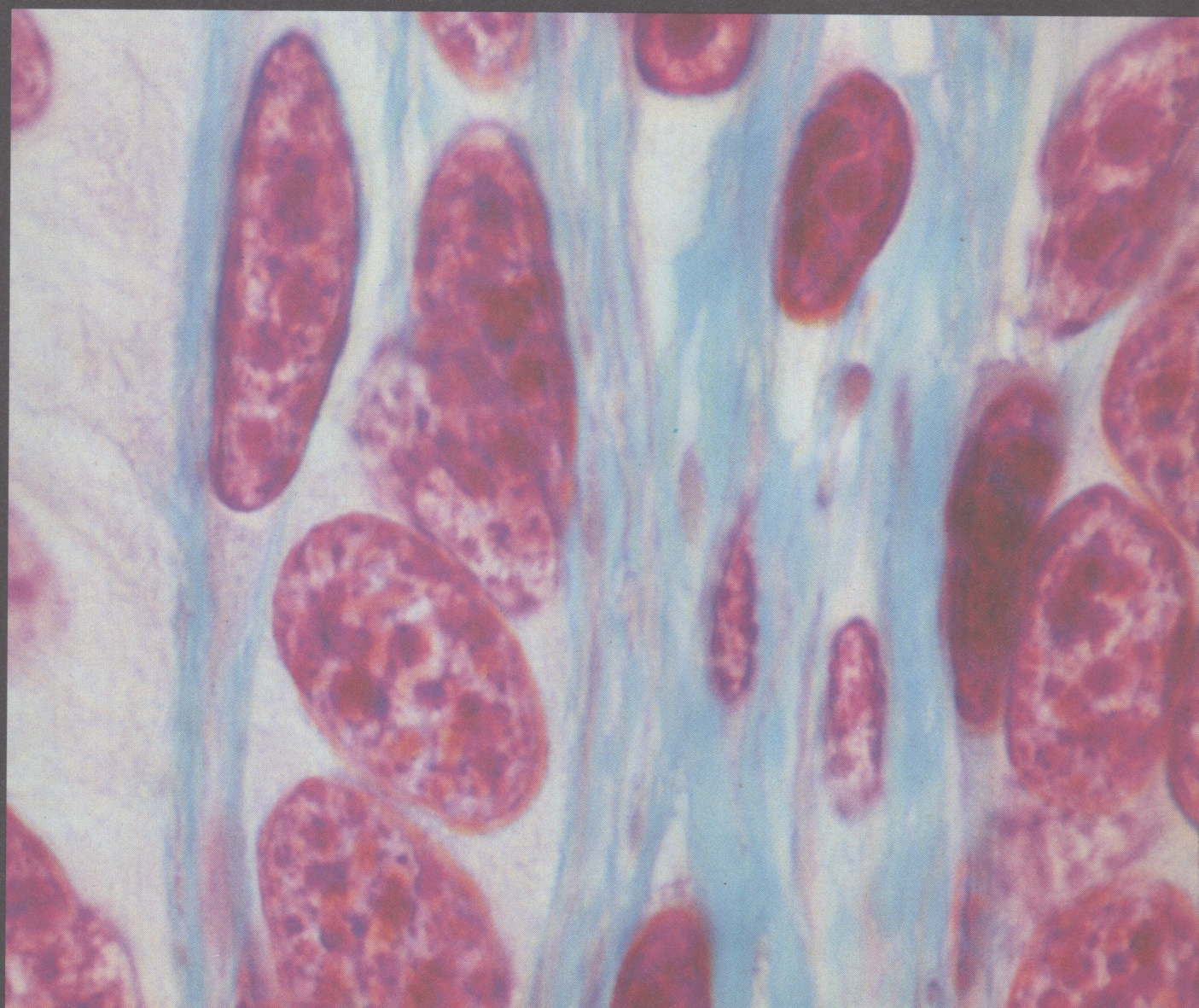


Left: Larry Miller photographed this Western cottonmouth (*Agkistrodon piscivorus*) at Reelfoot Lake in Tennessee. (Pentax ME Super with 90-mm lens at *f*/11, fill flash, Kodachrome.)



Right: Matthew J. Darcy of Laurel, Maryland, photographed this wild Chincoteague pony on Assateague Island off the Atlantic Coast. The origin of Chincoteague ponies is wrapped in mystery and legends of pirates and wrecked ships. (Pentax with 300-mm lens, Fuji 200 Super HG.)

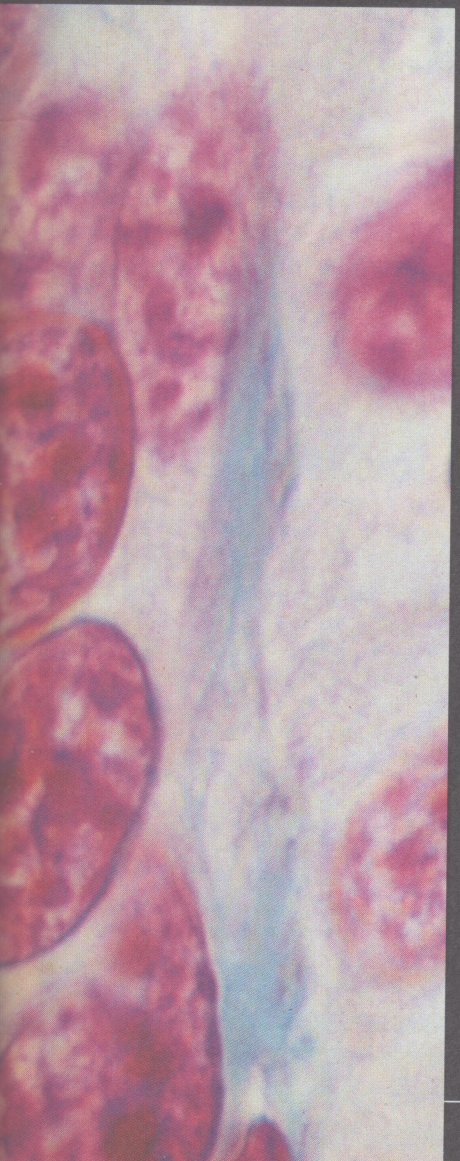
Below: Triple-stained section of the small intestine of a leopard frog (*Ran pipiens*) photographed at 40X with Kohler illumination by Danny B. Crain of Las Vegas, Nevada. (Nikon F3 with photomicrographic adaptor, Ektachrome 200.)

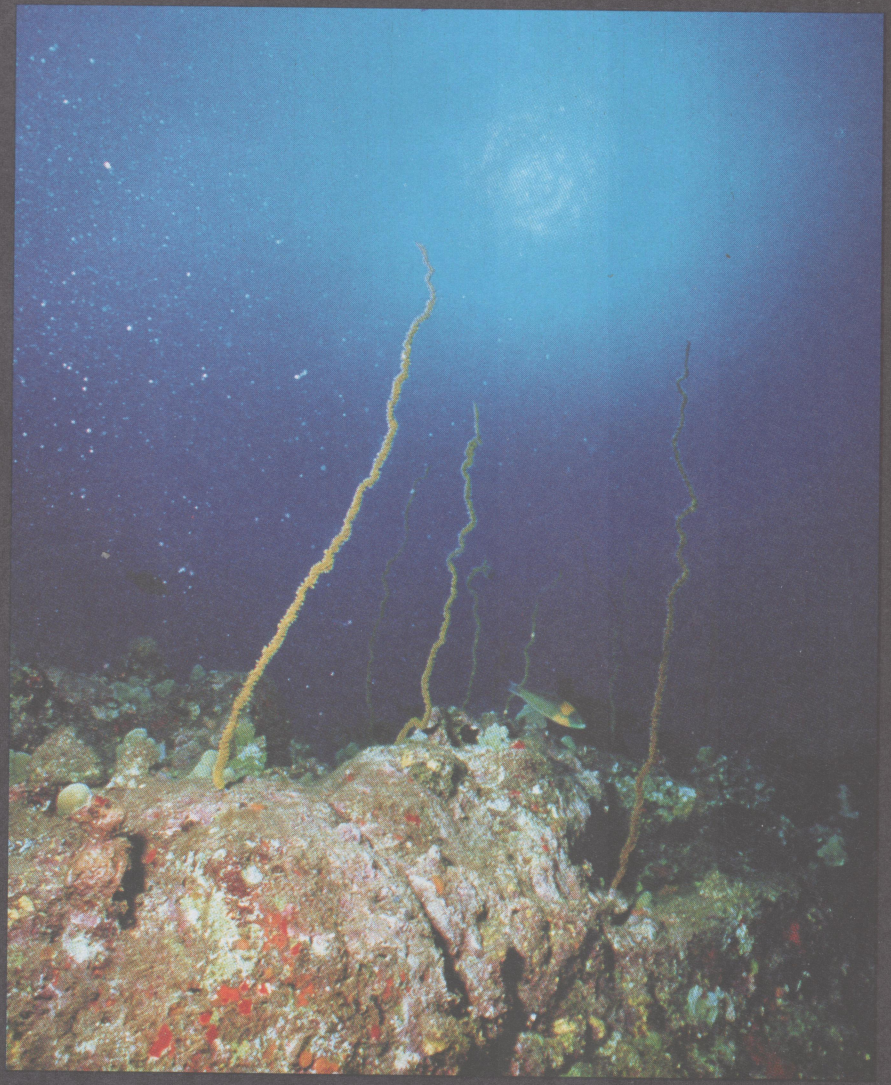




Left: Colleen Fantozzi of Grove, Illinois, photographed this monarch butterfly (*Danaus plexippus*). (Mamiya Sekor, Kodacolor 100.)

Below: Erik Stein photographed these hard corals of the order Antipatharia, commonly known as black coral (antipathes). (Nikonos with 28-mm lens using Ektachrome 100 at *f*/5.6 for 1/90th of a second.)





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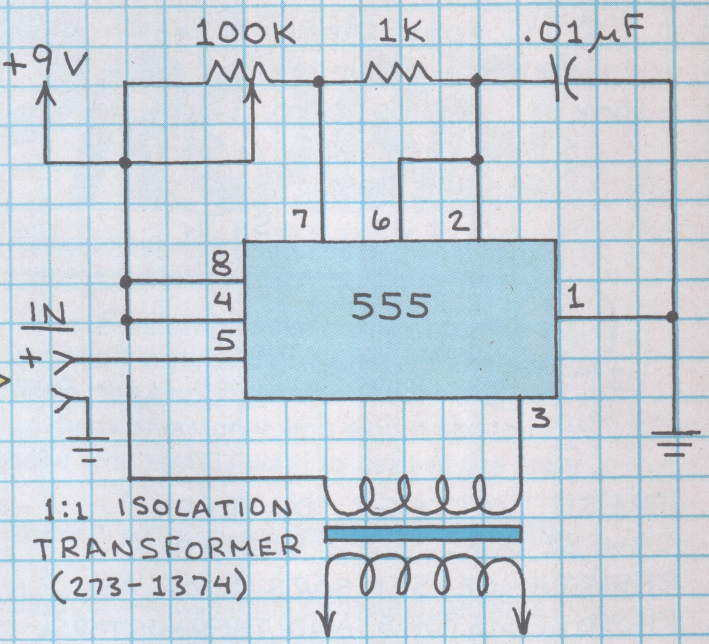
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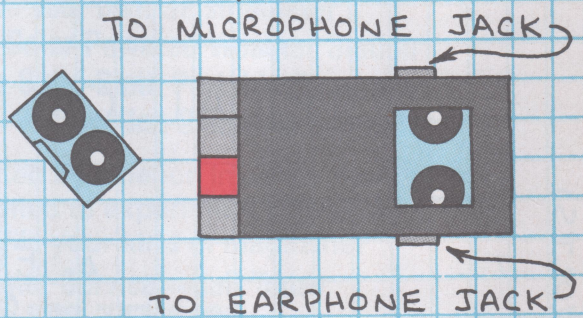
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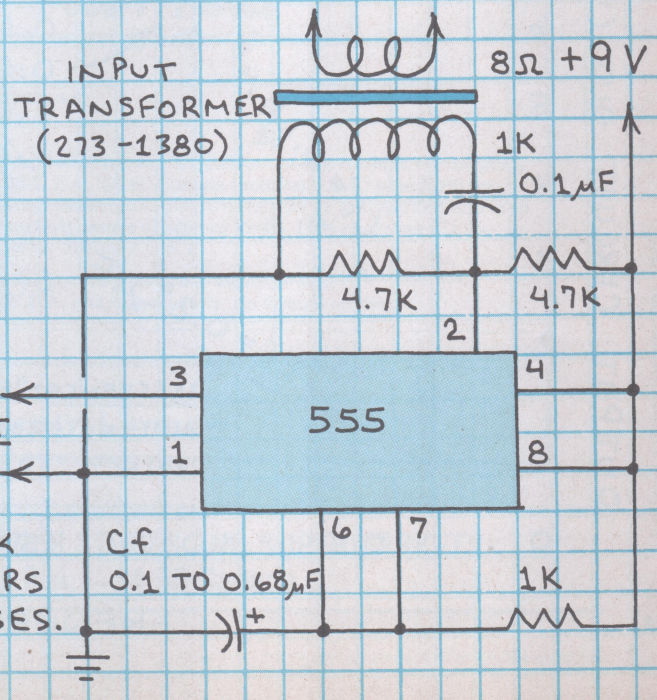
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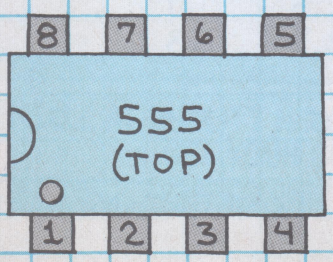
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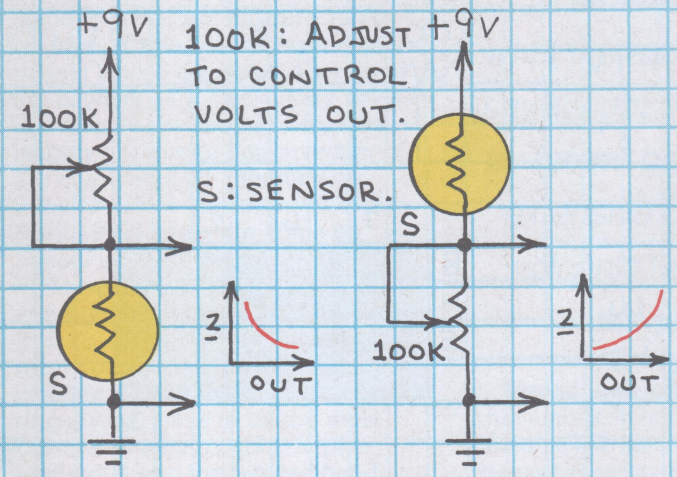




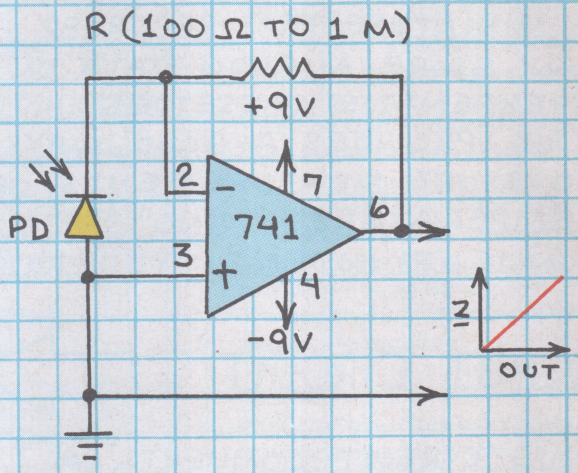
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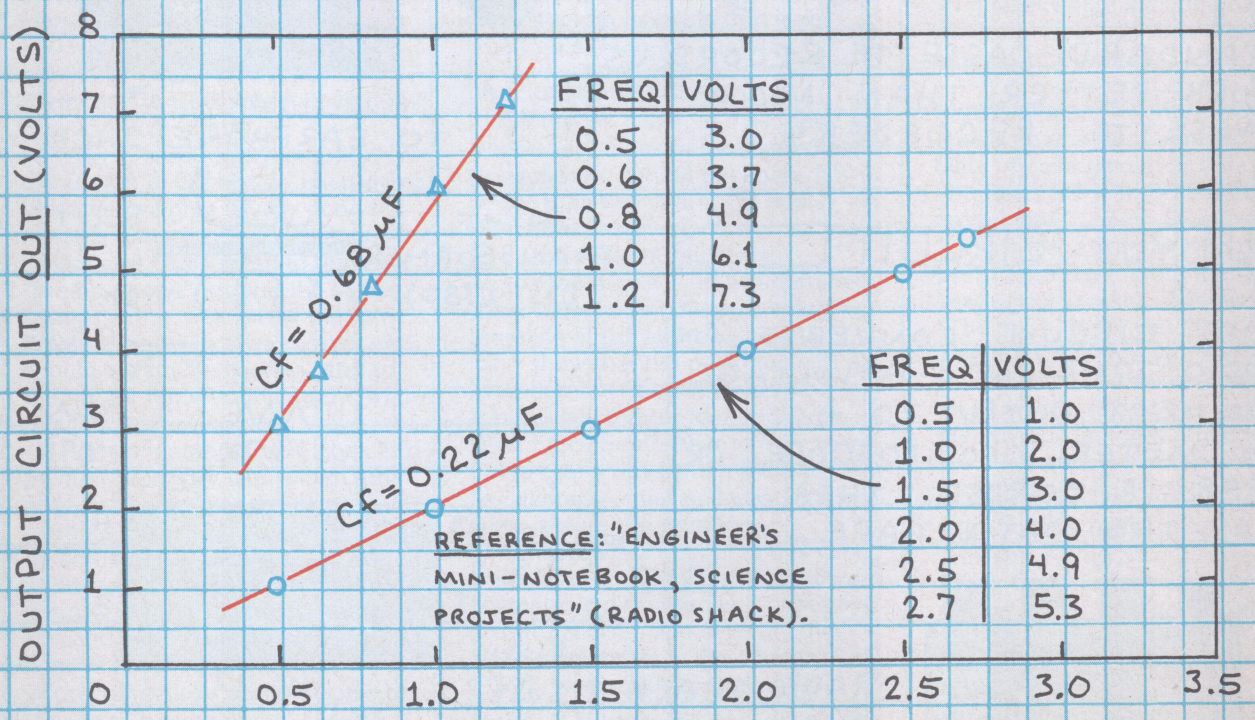


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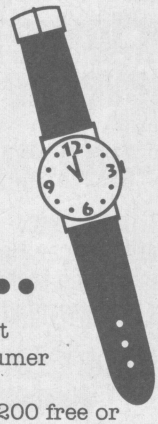
Continued from page 100

Now look at the two photographs of the oscilloscope display in Figures 10 and 11. Both photographs were taken when the microphone was withdrawn a few centimeters. Both patterns show interference between the incident wave and the reflected wave. The waveforms in these photographs are the algebraic sums of the two waves propagating in the pipe and are distorted from their original sine shape. The two patterns are essentially similar and represent microphone positions inside the PVC pipe that are only a few centimeters apart.

Going Further

There are other measurements you can make with the sound pipe. Since the propagation medium (air) can vary in temperature and relative humidity, try repeating these measurements at different times of the day and in different seasons. You might also try adding small sections of a sound absorbing material (such as foam) to the microphone "probe" to see what effect that has upon your measurements. ✳

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Updates and Corrections

(Continued from Page 6)

eggs, as in birds, the cell is the yolk and does not include the albumen or egg white."

We checked several references and agree with Carol. The *Encyclopedia Britannica*, for example, describes bird eggs as complete cells, with the shell being the outermost membrane. If you know of a published reference that excludes the shell of an egg from the definition of the outermost membrane of a cell, please send a note with the details.

Spreading the Word

Science PROBE! editors Forrest M. Mims, III, David S. Gunzel and Rita Breedlove handed out more than 4,000 copies of the April issue at the convention of the National Science Teachers Association in Boston this past March. They were overwhelmed by the enthusiastic response of the teachers they met.

Many teachers who are subscribers visited the *Science PROBE!* booth to give impromptu testimonials to their colleagues about the value of the magazine in science education. *Science PROBE!* contributors Stephen J, O'Meara and Donna Donovan-O'Meara also visited.

Debra A. Keddie, a teacher at the conference, presented a paper on how to adapt for classroom use a solar radiometer described in the April installment of "Science Notebook." Mims gave a talk about plans for the Science Probe Atmospheric Network.

Dozens of high school teachers and college professors around the country have distributed thousands of copies of *Science PROBE!* to teachers and students at many meetings and conferences. We're grateful to them and to the *Science PROBE!* authors and readers who help spread the word about *PROBE!*.

A good example is photographer and naturalist John V. Brown, who described the Panamanian rain forest in the July 1992 issue. Besides being a mentor at the New Mexico Museum of Natural History, Brown regularly conducts training sessions for science teachers. He took time from a training session in Lordsburg to send us a postcard expressing his delight over the layout of his rain forest article — and to let us know he gave out copies of *Science PROBE!* to teachers. ✳

The Third Planet

Continued from Page 19

that area and instead will cover only those that are more geologically remarkable. Local hiking and outdoors clubs will also be able to direct you to nearby hot springs.

If you have convenient access to a hot spring on a regular basis, there are several studies you can conduct. For example, does the temperature of the spring and amount of water flowing from it change with time? If you have access to a good chemistry or geology lab, you might also want to analyze the mineral content of the water and look for any variations in it. For most hot springs created by non-magma heating processes, any variations should be minimal and gradual. However, there have been cases of significant short-term temperature variations for hot springs found in hot spot areas.

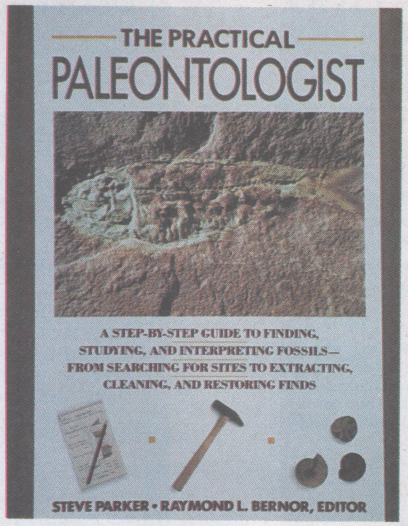
Sudden rises in hot spring temperature there indicate that magma is rising closer to the Earth's surface and may be an early warning of a possible volcanic eruption. For example, a sudden rise in the temperature of hot springs near Mammoth Lakes, California, in 1982 was one of the factors leading the U.S. Geological Survey to warn of possible volcanic activity in the region. The last volcanic eruptions near Mammoth Lakes took place approximately 600 years ago, and future eruptions are considered to be virtually inevitable. To help predict eruptions, the hot spring temperatures there are now carefully monitored on a regular basis.

It's worth locating hot springs near you, even if you're not interested in doing scientific observations or keeping an eye on potential volcanoes. One of the great treats of nature is soaking your feet in a hot spring after a long hike or, if the spring is big enough, soaking your entire body! ✳

ABOUT THE AUTHOR

Harry Helms is the author of 21 books and more than 200 magazine articles on various topics in electronics, computing and science. A founding partner of a technical publishing company, he is the operator of amateur radio station AA6FW. Harry gets personal with our world through astronomy, scuba diving and mountain climbing.

The Practical Paleontologist



Steve Parker's *The Practical Paleontologist* introduces readers to the kind of amateur science that can become either the most fascinating hobby you've ever had or the focus of a life work.

This enticing book summarizes the basic theories of paleontology, recaps its history, tells the reader how and where to make fossil-hunting trips, what to look for, what tools are necessary, how to extract fossils, and how to collect and preserve them.

Edited by Raymond L. Bernor, the book is an attractive mix of text, good photographs and excellent illustrations that are clearly marked and easy to understand.

The book gives a nicely balanced overview in an anecdotal style. The history review gives basic information such as dates and names, along with the human side. Ten-year-old Mary Anning's discovery of the first Ichthyosaurus specimens, for example, is summed up in a few short paragraphs that leave you feeling quite knowledgeable about her. Later the author relates an anecdote about the dinner Richard Owen held at the London Natural History Museum inside an unfinished Iguanodon model.

Parker does a good job of bringing to life what the Greeks named paleontology, their word for "ancient life."

Be aware, though, that the 160-page, 7- by 9.75-inch book is not large enough to cover the subject in significant detail. The discussion on how to find an appropriate site for exploration is a good example of the depth Parker gives his readers in his suggestions on using geological maps: "Using the contour lines, look for eroded hillsides. Where the contours are close together and correspond with bands of exposed rocks, there will be a likely site for fossil hunting. The whole map is covered by a reference grid, so you can pinpoint sites exactly and transfer the map reference to a more familiar road map."

Granted, *The Practical Paleontologist* is not enough information to guide you through a lifetime of fossil discovery. But not to worry, you'll be hooked — and off to the library for the rest of the tools you'll need.

The Practical Paleontologist is A Fireside Book published by Simon & Schuster Inc. of New York. It retails for $14.95. — *Rita Breedlove*

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The Art of Science is an intellectually rigorous book, but is written in an engaging, often humorous style that vividly conveys the excitement of scientific experimentation and discovery. No matter what area of science interests you, *The Art of Science* will give you the intellectual "tool kit" you need to do true scientific work to professional standards!

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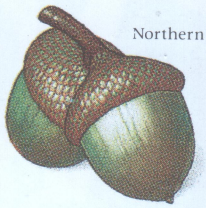
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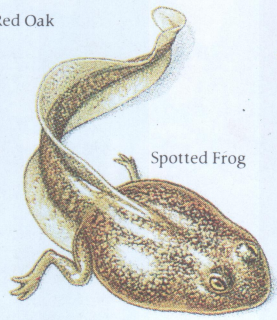
How life begins in the forest.



American Robin



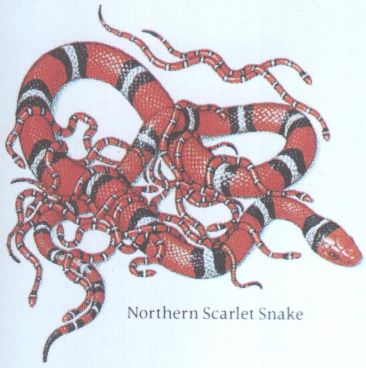
Northern Red Oak



Spotted Frog



Beaver



Northern Scarlet Snake



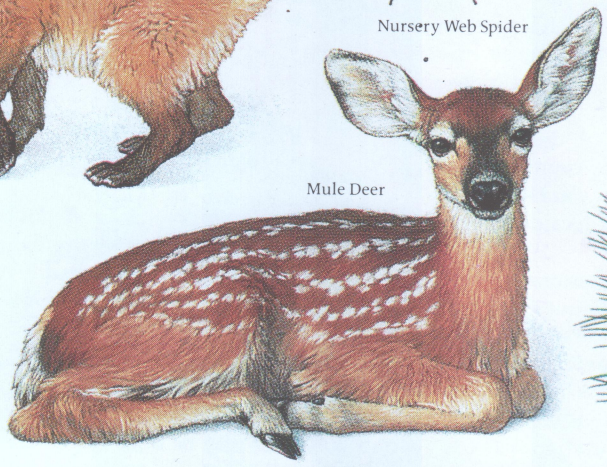
Red Fox



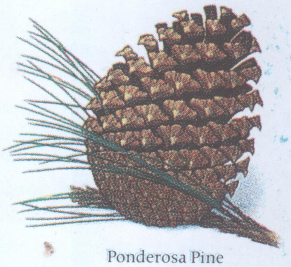
Nursery Web Spider



Barn Owl

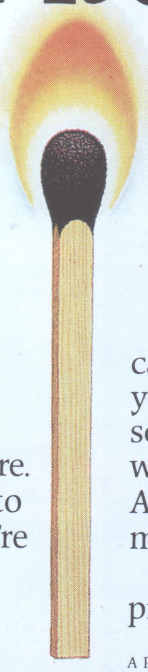


Mule Deer



Ponderosa Pine

How it ends.



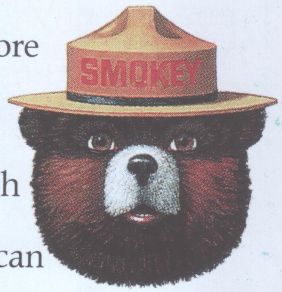
One match.

That's all it takes to destroy a forest and every creature, great and small, who lives there.

So it's especially important to be careful with fire when you're in the forest.

Always make sure your campfire is out cold before you leave it. If you see someone being careless with fire, call an adult. And never, ever play with matches.

Remember, only you can prevent forest fires.



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There is a thriving professional service steeped in high-tech techniques that you can become a part of! But first, you must know and understand Countersurveilance Technology. Your very first insight into this highly rewarding field is made possible by a video VHS presentation that you cannot view on broadcast television, satellite, or cable. It presents an informative program prepared by professionals in the field who know their industry, its techniques, kinks and loopholes. Men who can tell you more in 45 minutes in a straightforward, exclusive talk than was ever attempted before.

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You know that the Russians secretly installed countless microphones in the concrete work of the American Embassy building in Moscow. They converted what was to be an embassy and private residence into the most sophisticated recording studio the world had ever known. The building had to be torn down in order to remove all the bugs.

Stolen Information

The open taps from where the information pours out may be from FAX's, computer communications, telephone calls, and everyday business meetings and lunchtime encounters. Businessmen need counselling on how to eliminate this information drain. Basic telephone use coupled with the user's understanding that someone may be listening or recording vital data and information greatly reduces the opportunity for others to purloin meaningful information.

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The professional discussions seen on the TV screen in your home reveals how to detect and disable wiretaps, midget radio-frequency transmitters, and other bugs, plus when to use disinformation to confuse the unwanted listener, and the technique of voice scrambling telephone communications. In fact, do you know how to look for a bug, where to look for a bug, and what to do when you find it?

Bugs of a very small size are easy to build and they can be placed quickly in a matter of seconds, in any object or room. Today you may have used a telephone handset that was bugged. It probably contained three bugs. One was a phony bug to fool you into believing you found a bug and secured the telephone. The second bug placates the investigator when he finds the real thing! And the third bug is found only by the professional, who continued to search just in case there were more bugs.

The professional is not without his tools. Special equipment has been designed so that the professional can sweep a room so that he can detect voice-activated (VOX) and remote-activated bugs. Some of this equipment can be operated by novices, others require a trained countersurveillance professional.

The professionals viewed on your television screen reveal information on the latest technological advances like laser-beam snoopers that are installed hundreds of feet away from the room they snoop on. The professionals disclose that computers yield information too easily.

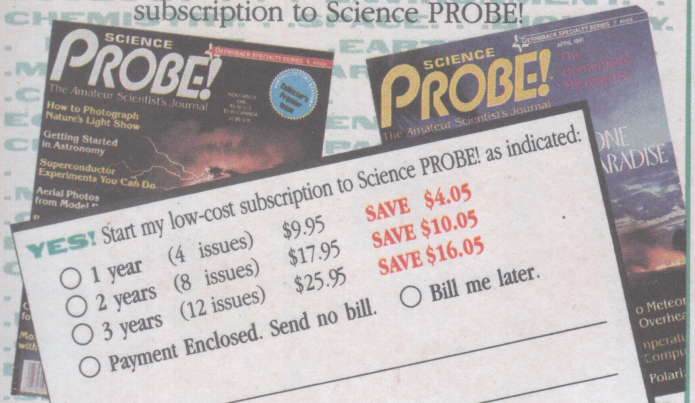
This advertisement was not written by a countersurveillance professional, but by a beginner whose only experience came from viewing the video tape in the privacy of his home. After you review the video carefully and understand its contents, you have taken the first important step in either acquiring professional help with your surveillance problems, or you may very well consider a career as a countersurveillance professional.

The Dollars You Save

To obtain the information contained in the video VHS cassette, you would attend a professional seminar costing $350-750 and possibly pay hundreds of dollars more if you had to travel to a distant city to attend. Now, for only $49.95 (plus $4.00 P&H) you can view ***Countersurveillance Techniques*** at home and take refresher views often. To obtain your copy, complete the coupon below or call toll free.

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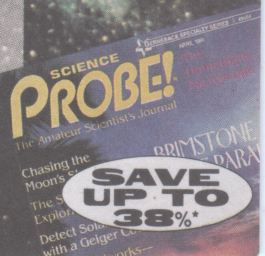
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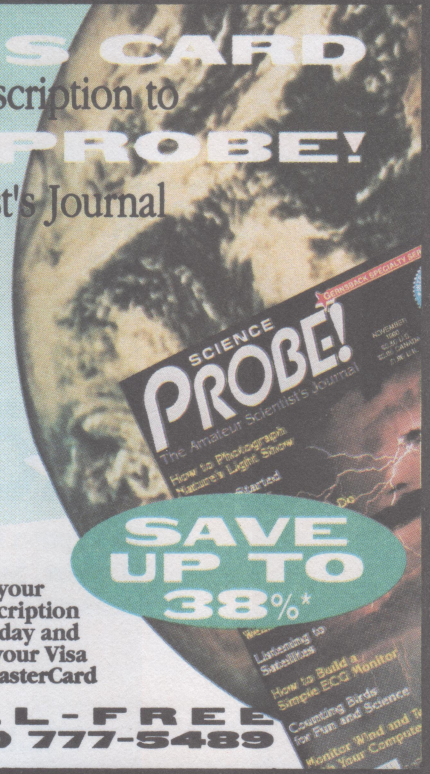
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